and is very approximately proportional to the actual pressure, and hence decreases regularly with elevation.

(6) The amplitude of the twelve-hourly component of the oscillation for the mean day of the year (or the annual value of U_2) decreases with latitude according to the following law (ϕ denoting the latitude) $U_2 = \cdot984 - \cdot188 \sin. \phi - \cdot978 \sin.^2\phi$ in millimetres or $U_2 = \cdot0397 - \cdot0074 \sin. \phi - \cdot0385 \sin^2\phi$ in English measure. These formulæ give very approximate results up to Lat. 60°. Another approximate and simpler formula is:—

$U_2 = -\cdot232 + 1\cdot184 \cos^2\phi$ in French units and $= -\cdot089 + \cdot475 \cos^2 \phi$ in English units.

(7) The following gives normal values of U_2 for the mean day of the year in different latitudes:—

Latitude.	Amplitude.	
	Millimetre.	Inch
0°	·98	·0386
5°	·96	·0378
10°	·92	·0362
15°	·87	·0342
20°	·81	·0318
25°	·73	·0287
30°	·65	·0256
35°	·55	·0216
40°	·46	·0181

(D) Epochs and periods of the second or twelve hourly component :—

(1) The mean value of u_2 is 155°, corresponding to maximum epochs of 9-50 A.M. and P.M.

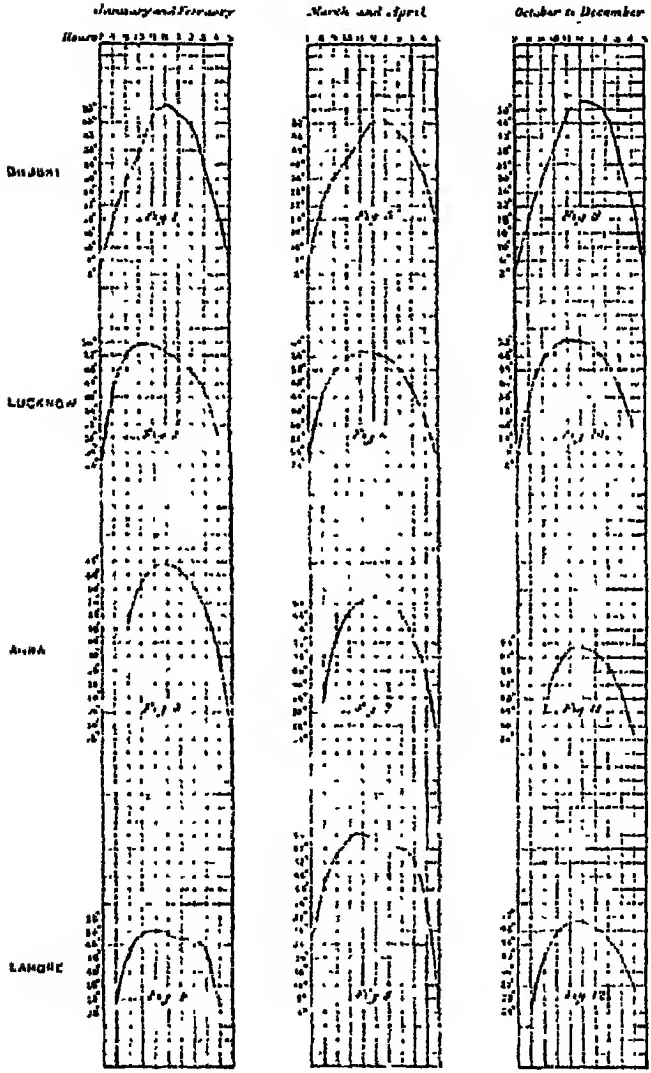
(2) There are large areas or regions where the epochs are accelerated and other equally large regions in which they are retarded. Stations in the interior and on the east coast of Asia shew largish positive deviations of u_2 from this value, averaging twelve minutes in amount. At oceanic stations in the tropics there is an acceleration of the epochs averaging eight minutes.

(3) Stations between 10°N. and 20°S. Lat. give a mean value of $u_2 = 158°$ nearly, corresponding to an acceleration of the maximum epoch by six minutes.

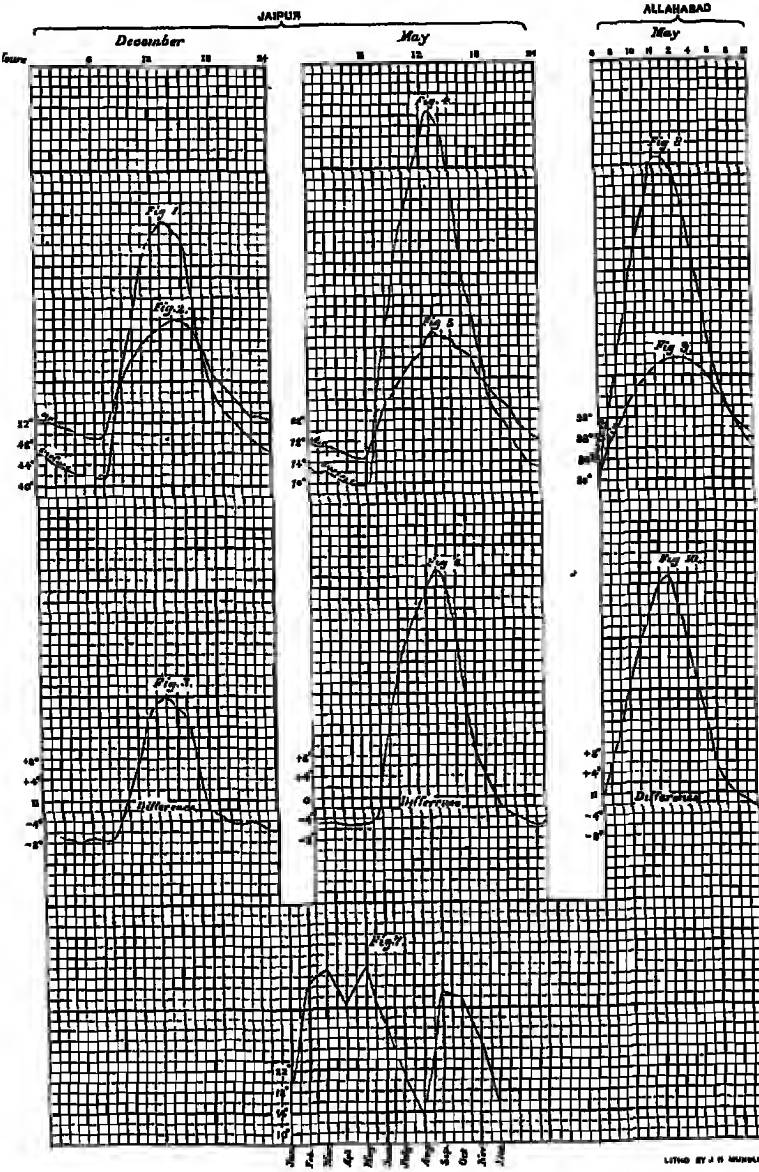
(4) The most important feature of the twelve-hourly component is its uniformity in character between the 55°N. and 55°S. parallels of latitude. This component is in fact to a remarkable extent independent of local meteorological conditons.

(5) u_2 (more especially when expressed in time) varies very slightly throughout the year. It is slightly less than the mean in summer and slightly greater in winter, indicating that the maximum epochs are slightly accelerated in winter and slightly delayed in summer,

DIURNAL VARIATION OF MEAN EXCESS OF INSOLATION TEMPERATURE AT THE HOURS OF APPARENT TIME IN—

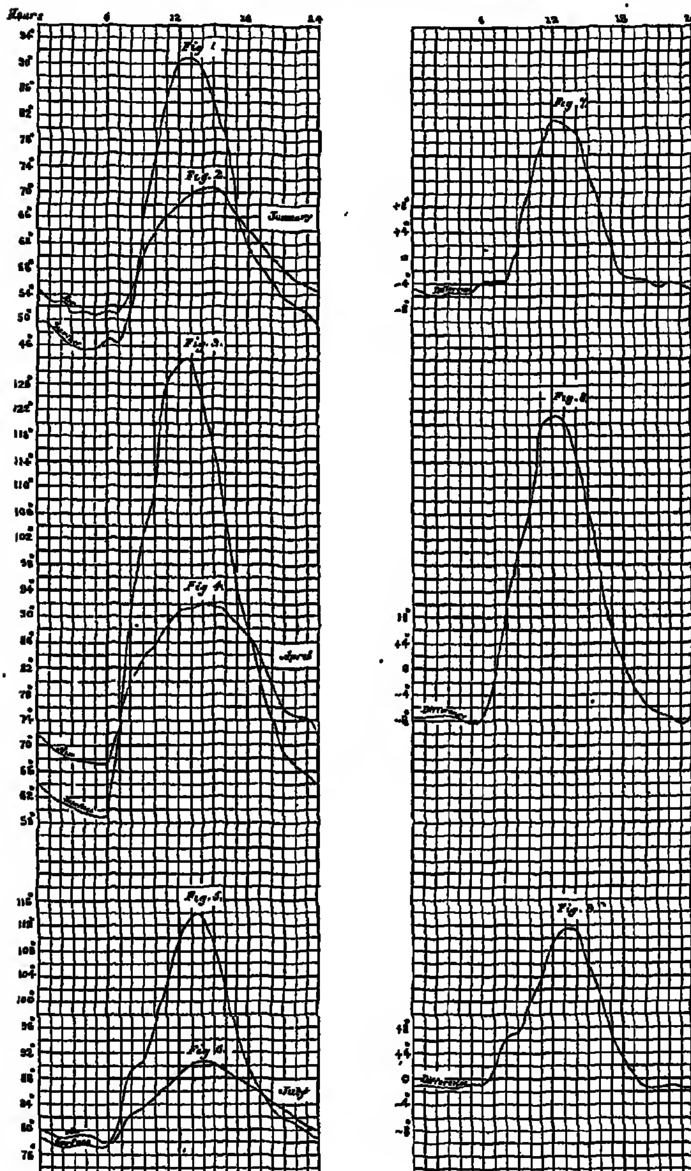


DIURNAL VARIATION OF AIR TEMPERATURE, SURFACE TEMPERATURE AND SURFACE MINUS AIR TEMPERATURE AT JAIPUR AND ALLAHABAD.

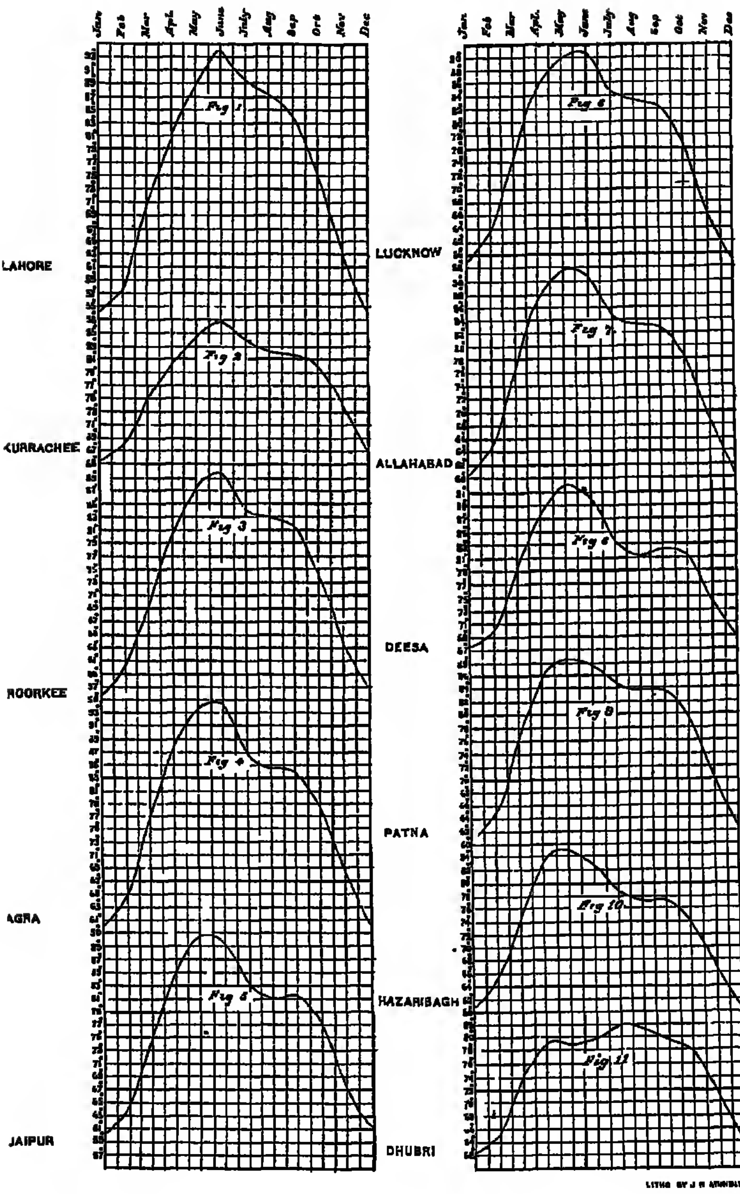


LITHO BY J. R. MUNDLE.

DIURNAL VARIATION OF AIR TEMPERATURE, SURFACE TEMPERATURE AND SURFACE MINUS AIR TEMPERATURE AT JAIPUR IN JANUARY, APRIL AND JULY.

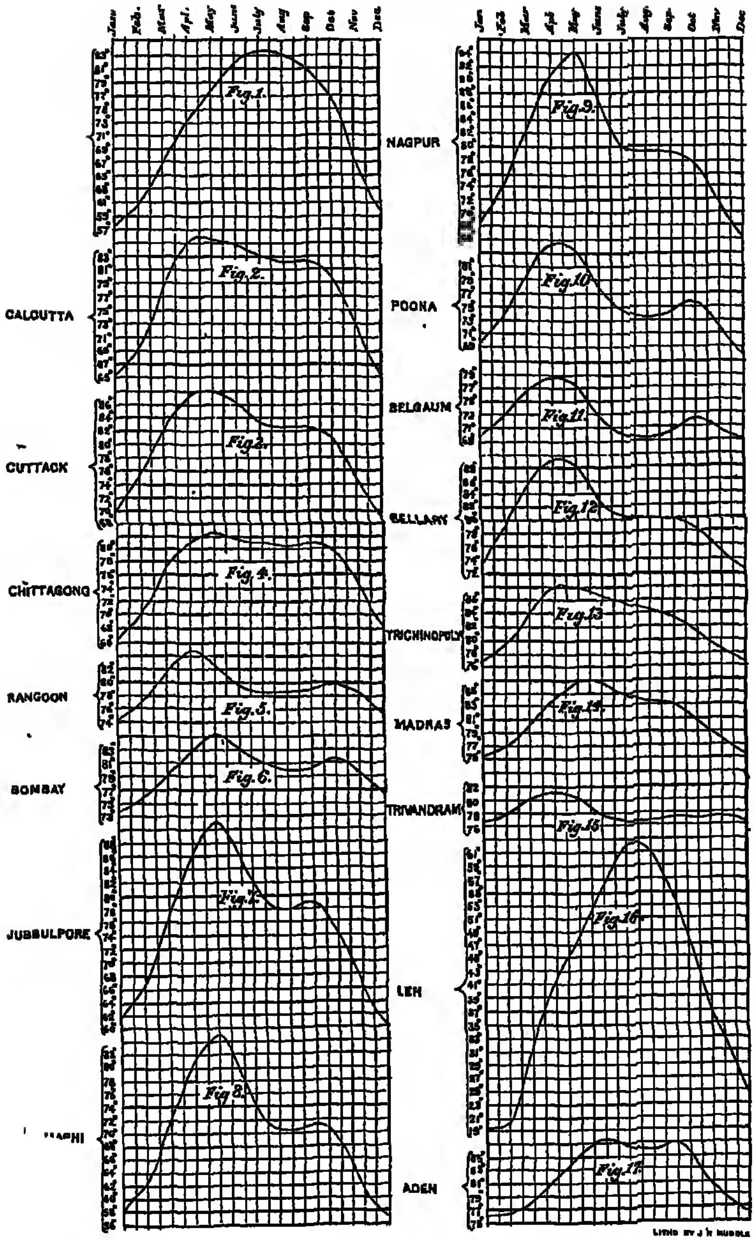


ANNUAL VARIATION OF TEMPERATURE IN



LITHO BY J. R. ARNOLD

ANNUAL VARIATION OF TEMPERATURE IN...



LITHO BY J H RUDDLE

(6) Hence there is a feeble relation between the epochs of the twelve-hourly component and the seasons of the year

(E) Amplitude of the third or eight-hourly component:—

(1) U_3 is almost independent of the latitude.

(2) U_3 exhibits a strongly pronounced yearly variation, its maximum being in January and minimum in June or July.

(3) The third component has a strongly marked annual variation, the maxima amplitudes being four to six times greater than the minima. The amplitudes are very small in spring and in autumn when the sun is over the equator. Their absolute or primary maxima values are in the winter of each hemisphere and the secondary maxima in summer. The annual variation of the amplitude of the third component is hence related to general seasonal changes, and not to local conditions.

(4) The ratio of U_3 to U_2 or to U_1 decreases with increasing latitude, or in other words, the third component decreases in importance with increasing latitude.

(5) As a conclusion from these facts Dr. Hann considers that the regularity of the annual variation of so small a quantity in all cases is so remarkable as to strongly suggest that the third component is not an accidental local or time modification of the phenomenon but is a real and independent constituent of the daily oscillation.

In the memoir on the subject entitled "Weitere Untersuchungen über die Tägliche Oscillation des Barometers," Dr. Hann deals chiefly with the more important features of the diurnal oscillation of pressure as observed on mountain peaks and in mountain valleys, and gives a theoretical explanation of the peculiarities thus disclosed.

The following is a statement of the more characteristic features of the diurnal oscillation on mountain peaks and in mountain valleys:—

I.—*On mountain peaks.*—The following is a summary of the more characteristic features of the diurnal oscillation of the barometer on mountain peaks or ridges —

(*a*) The morning minimum occurs at about the normal time, the amount or amplitude of the depression increasing with elevation.

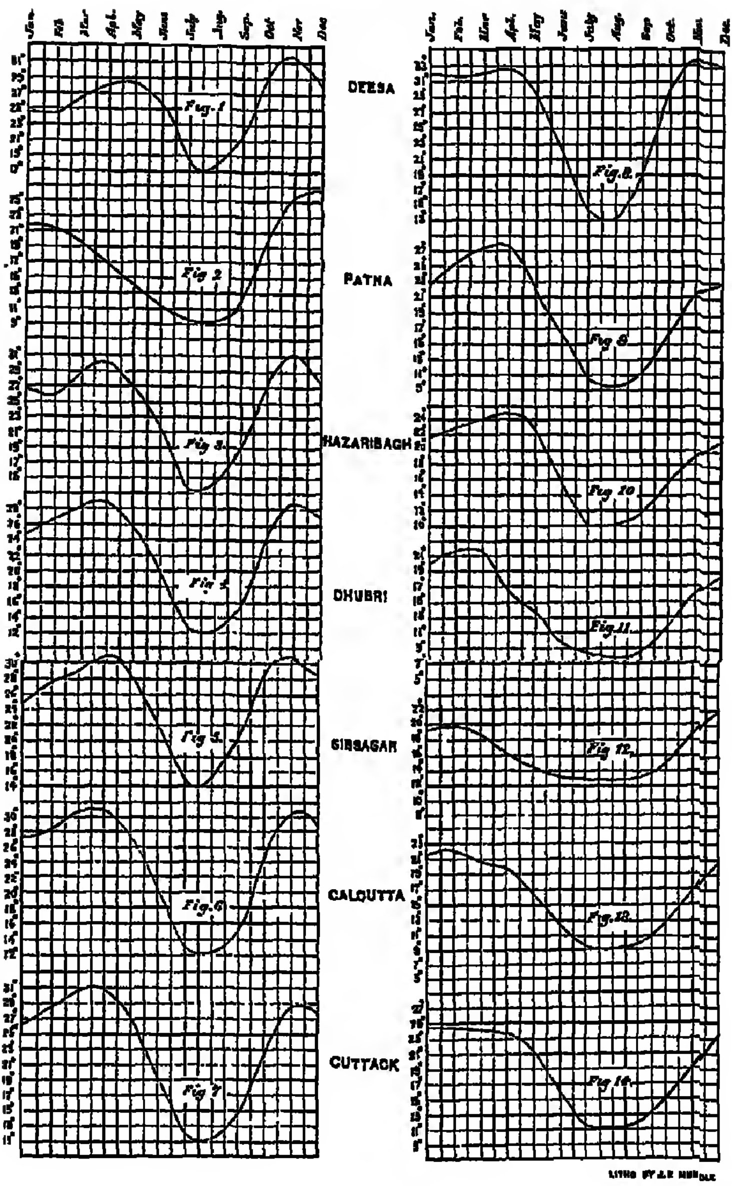
(*b*) The morning maximum is delayed or retarded by amounts depending on the altitude. At high stations (above 10,000 feet) its epoch is about 3 P.M. or 4 P.M.

(*c*) The afternoon minimum is slightly retarded at mountain stations (*e.g.*, one to two hours on the Sonnblick).

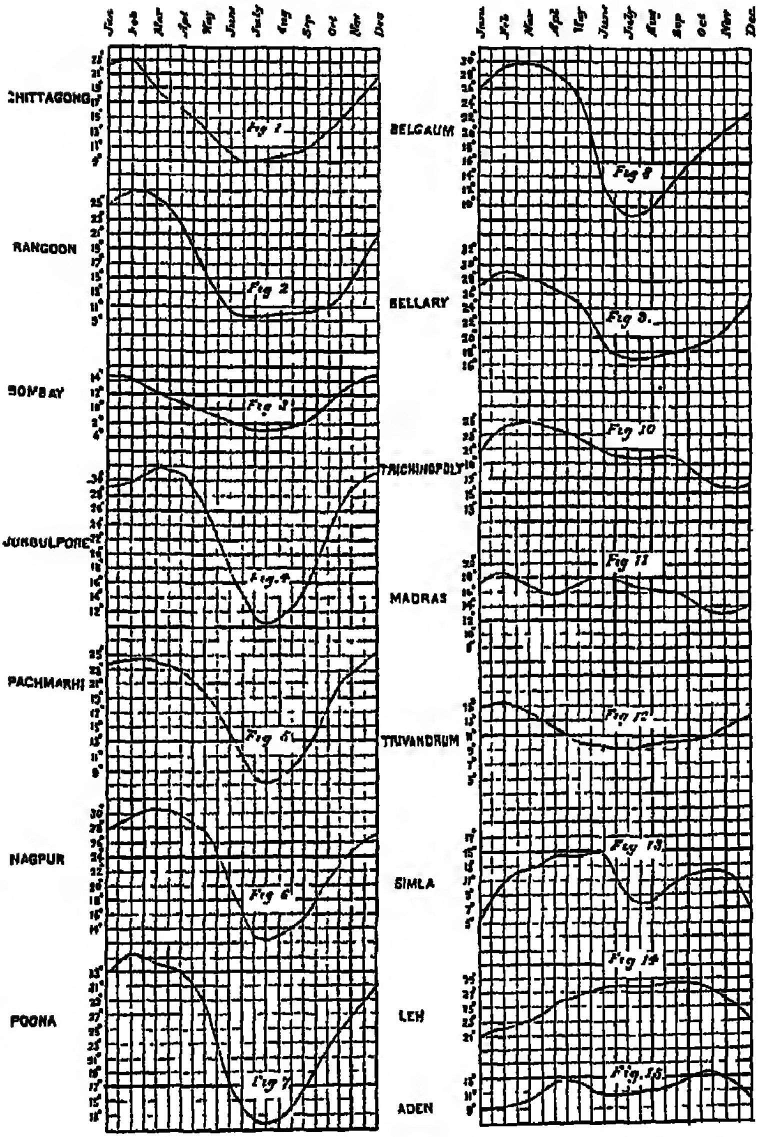
(*d*) The evening maximum occurs at about the normal time (10 P.M.) and is more pronounced than the morning maximum, the excess of the former over the latter increasing with elevation.

(*e*) On mountain peaks, in consequence of the peculiarities stated above, the diurnal pressure curve tends to approach in form to the diurnal temperature curve, the similarity in form increasing with elevation. The corresponding absolute maximum and minimum epochs occur later in the pressure than in the temperature curves. The absolute minimum corresponds with the minimum temperature and the secondary maximum with the maximum of temperature in the diurnal variation of that element.

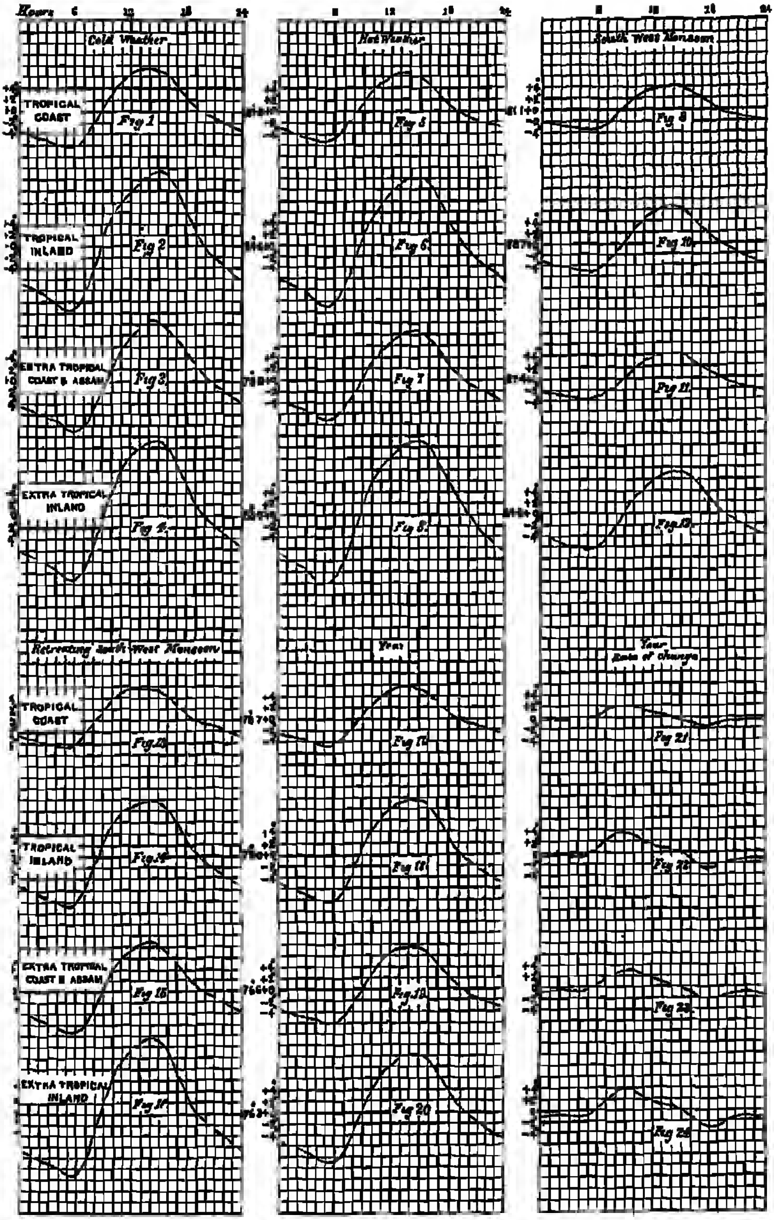
ANNUAL VARIATION OF THE MEAN DAILY RANGE OF TEMPERATURE



ANNUAL VARIATION OF THE MEAN DAILY RANGE OF TEMPERATURE



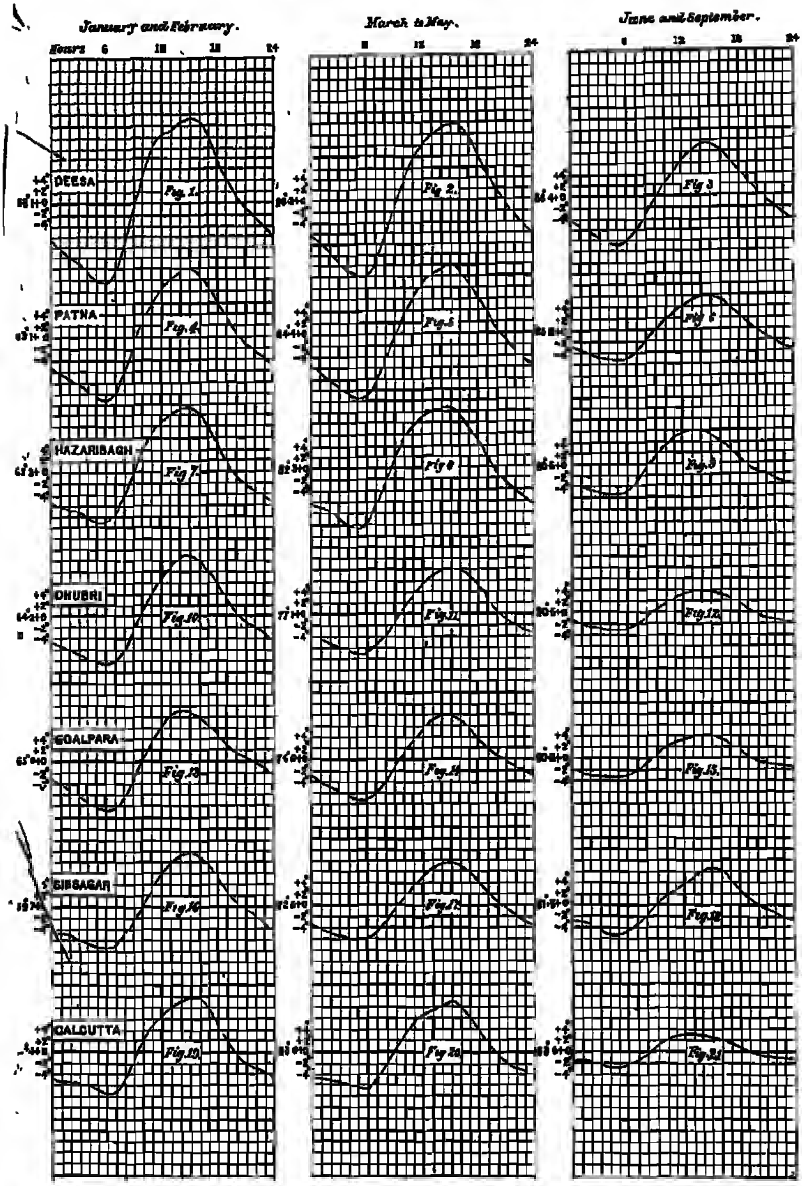
DIURNAL VARIATION OF TEMPERATURE



LITHO BY J M MURDLE

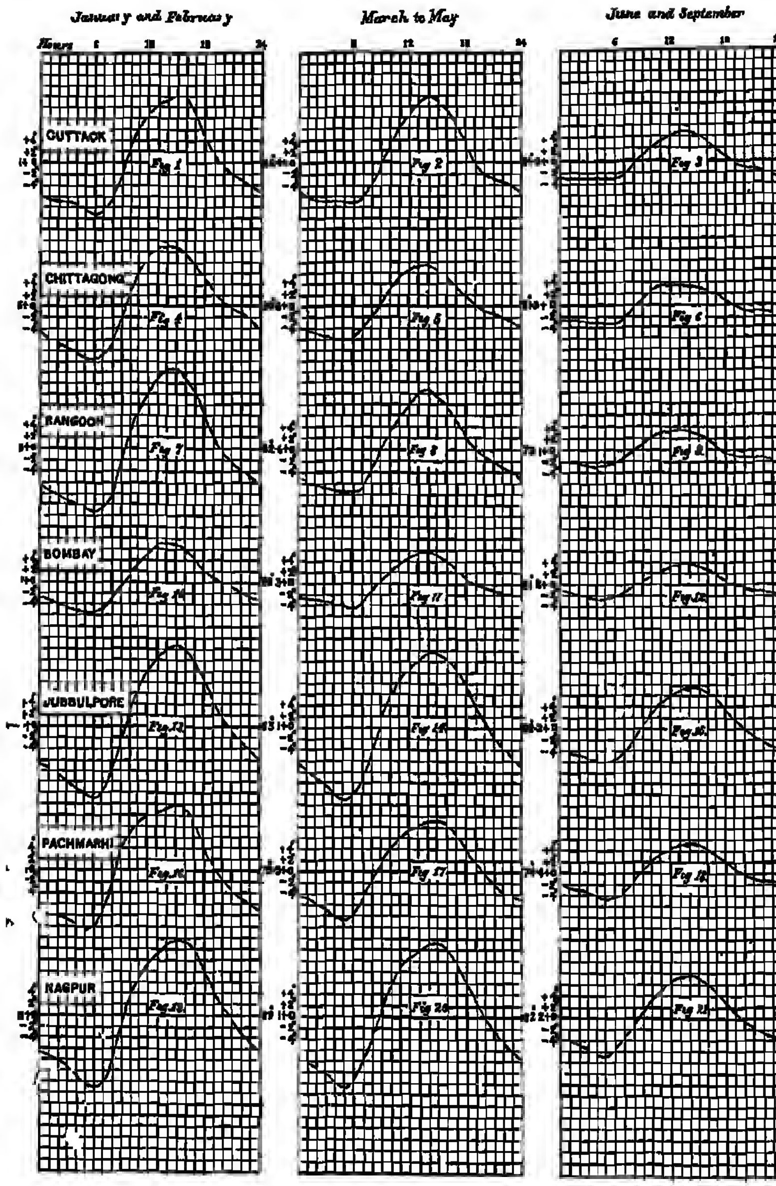
Plate XLV . .	Fig^{s}	1—28	Diurnal variation of cloud for the period October to December and for the year at twenty seven stations
„ XLVI . .	„	1—26	
„ XLVII . .	„	1—13	Diurnal variation of cloud at Srinagar (*Kashmir*) for each month of the year and the year
„ XLVIII .	„	1—4	Chart showing normal mean pressure and winds for January, March, May and June.
„ XLIX . .	„	1—4	Chart showing normal mean pressure and winds for August, October, December and year
„ L	„	1—4	Chart showing normal pressure and winds at 8 A.M. and 4 P.M., in January and April
„ LI . .	„	1—4	Chart showing normal pressure and winds at 8 A.M., and 4 P.M., in July and November.
„ LII . .	„	1—29	Annual variation of wind velocity in miles per hour for twenty nine stations
„ LIII . .	„	1—16	Diurnal variation of wind velocity in miles per hour in two seasons (*viz.*, the cold weather and hot weather seasons) for fifteen stations
„ LIV . .	„	1—14	
„ LV .	„	1—16	Diurnal variation of wind velocity in miles per hour in two seasons (*viz.*, the south west monsoon and retreating south west monsoon periods) for fifteen stations.
„ LVI .	„	1—14	
„ LVII . .	„	1—30	Diurnal variation of pressure for three periods of the year, (*viz.*, January and February, March to May and June and September) at thirty stations
„ LVIII . .	„	1—30	
„ LIX . .	„	1—30	
„ LX . .	„	1—30	Diurnal variation of pressure for two periods of the year (*viz.* July and August, and October to December) and for the year at thirty stations
„ LXI . .	„	1—30	
„ LXII . .	„	1—30	
„ LXIII . .	„	1—13	Diurnal variation of pressure at Srinagar (*Kashmir*) for each month of the year and the year
„ LXIV . .	„	1—8	Diurnal variation of the air and surface temperature at Jaipur in December, May, July and August
„ „ .	„	9 and 10	Diurnal variation of the air temperature and of the rate of change of the air temperature in Northern India in the dry season
„ „ . .	„	11 and 12	Diurnal variation of the maximum insolation temperature and of the rate of change of the maximum insolation temperature in Northern India in the dry season
„ LXV . . „ LXVI „ LXVII			Annual variation of the amplitudes of U_1 and U_2 of air pressure and temperature, maximum insolation temperature and diurnal range of temperature for fifteen stations
„ LXVIII „ LXIX „ LXX .			Annual variation of temperature, aqueous vapour pressure and cloud and the amplitudes of U_1 and U_2 of aqueous vapour pressure for fifteen stations
„ LXXI .			Annual variation [illegible] amplitudes of U_1 and U_2 of cloud proportion at se[illegible] stations
„ LXXII . .	„	1—6	Diurnal variation of U_1, U_2 and U_3 *plus* U_4 of pressure for the typical months of the three seasons of the year at Jaipur and Allahabad
„ LXXIII .	„	1—6	Diurnal variation of U_1, U_2 and U_3 *plus* U_4 of temperature for the typical months of the three seasons of the year at Jaipur and Allahabad

DIURNAL VARIATION OF TEMPERATURE IN



LITHO BY J. N. MUNGLE.

DIURNAL VARIATION OF TEMPERATURE IN



LITHO BY J N HUNDLE

(*f*) The difference in amount between the evening maximum and the early morning minimum (or the amplitude of the night oscillation) increases with elevation This is, on the whole, the most characteristic feature of the diurnal pressure oscillation on mountain peaks

(*g*) u_1 differs little on mountain peaks on the Alps and averages 175°, corresponding to the epoch of the maximum phase at 6 20 P M. It is hence almost exactly opposite in phase to the corresponding component of the oscillation at the plains station

(*h*) u_1 increases in amount from winter (140°) to summer (188°) so that at the Alpine mountain crest stations the epoch of the maximum is about 2 hours after the mean in winter and one hour before it in summer This difference of epoch with the season *decreases* in amount with elevation

(*i*) The amplitude of the 24 hourly component increases in relative importance with elevation, and also from winter to summer.

(*j*) The epoch of the maximum phase of the 12-hourly component is delayed with increasing elevation The rate of retardation with elevation is small in the tropics and increases with latitude. The retardation on the Alps is on the mean of the year 44 minutes and increases from 24 minutes in winter to 64 minutes in summer

(*k*) U_1 shews no regular law of decrease with elevation

II.—*In mountain valleys*—The following is a summary of the chief features of the diurnal oscillation of pressure in deep mountain valleys:—

(1) The early morning minimum occurs at the normal hour 4 A M, but is very feebly marked

(2) The morning maximum is between 7 A M and 8 A M, and hence from two or three hours earlier than in open level plains

(3) The afternoon minimum is slightly delayed, occurring between 4 P M and 5 P M. and is very marked This is the most characteristic feature of the diurnal oscillation in mountain valleys

(4) The evening maximum is delayed until about midnight

(5) The interval between the morning and evening maximum averages 17 hours

(6) The phase for stations in mountain valleys in the Alps averages 37°, corresponding to the epoch of 3 30 A M for the maximum phase. Hence the 24 hourly component is almost opposite in phase in mountain valleys and mountain crests

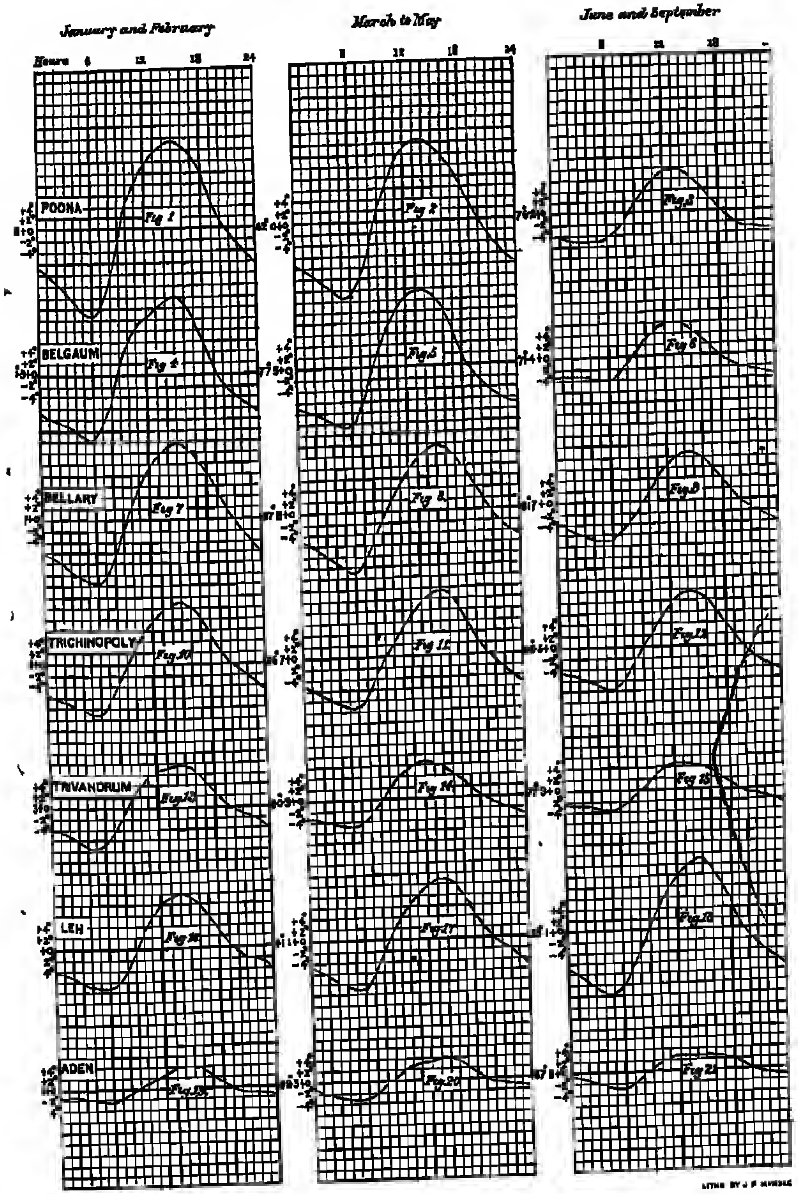
The following important remarks relating to the second component are taken from Dr Hann's paper entitled "Further contributions to the foundation of a theory of the daily barometric oscillation" which appeared in the *Meteorologische Zeitschrift*, October 1898, and a translation of which is given in the Quarterly Journal of the Royal Meteorological Society, Vol XXV No 109, for January 1899 —

"The observed daily variations of wind and of temperature do not stand in as close a relation to the diurnal barometric oscillation as has hitherto been assumed

'As the periodical action of the sun's rays on the upper strata of the atmosphere, recurring day by day, must produce periodical movements of great regularity (an oscillation of the entire mass of the atmosphere), it is easy to see that this can explain the typical character of the diurnal barometric oscillation, while the local differences of the earth's surface represent the modifying element'

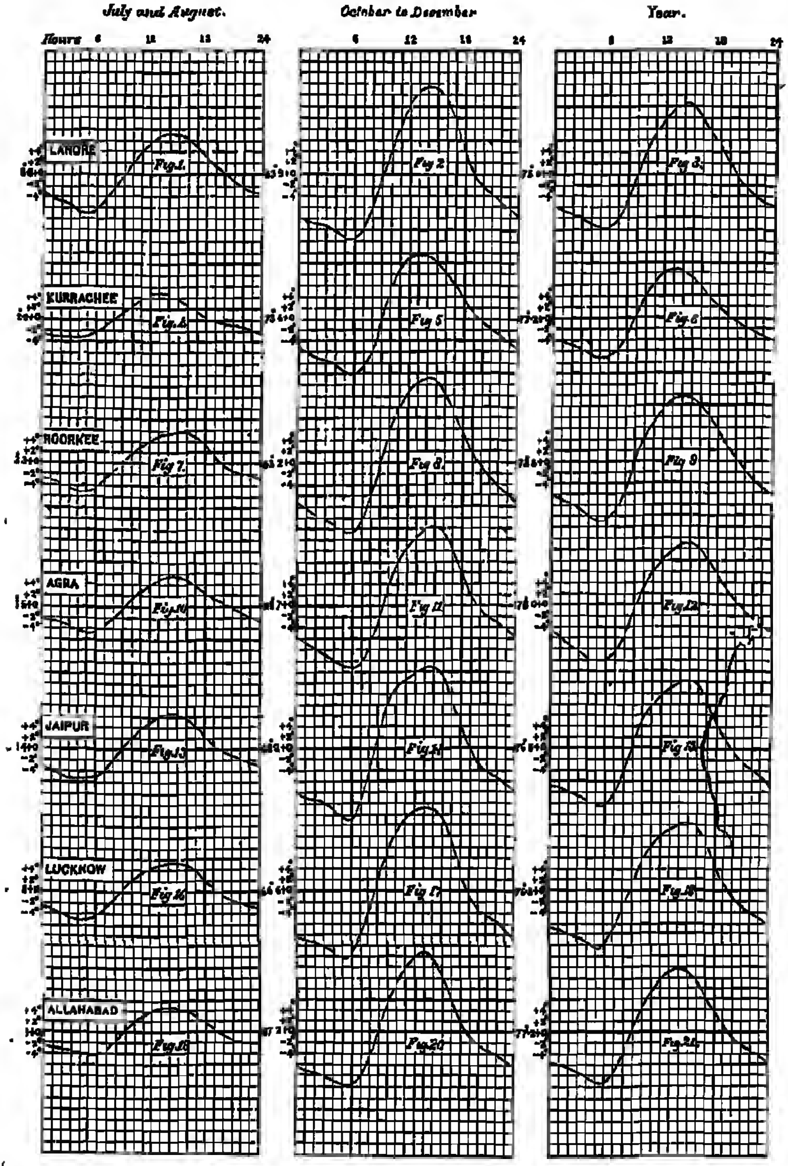
2

DIURNAL VARIATION OF TEMPERATURE IN



LITHO BY J F MUNDLE

DIURNAL VARIATION OF TEMPERATURE IN



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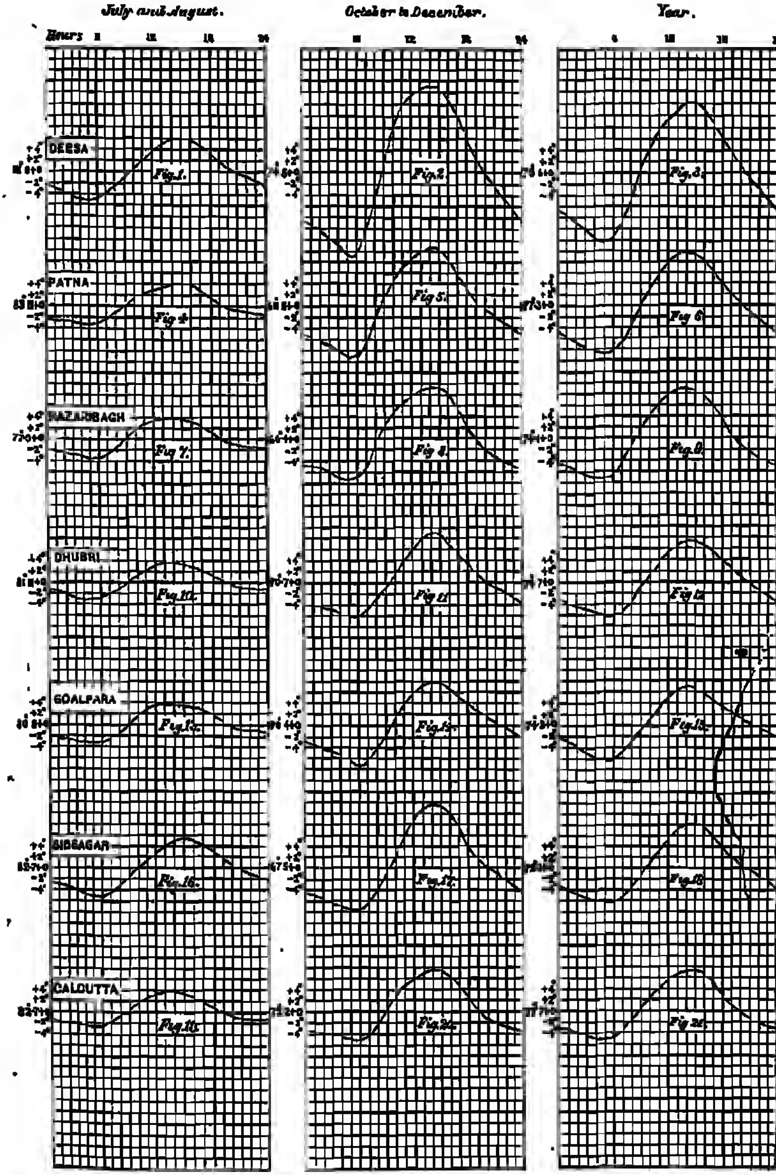
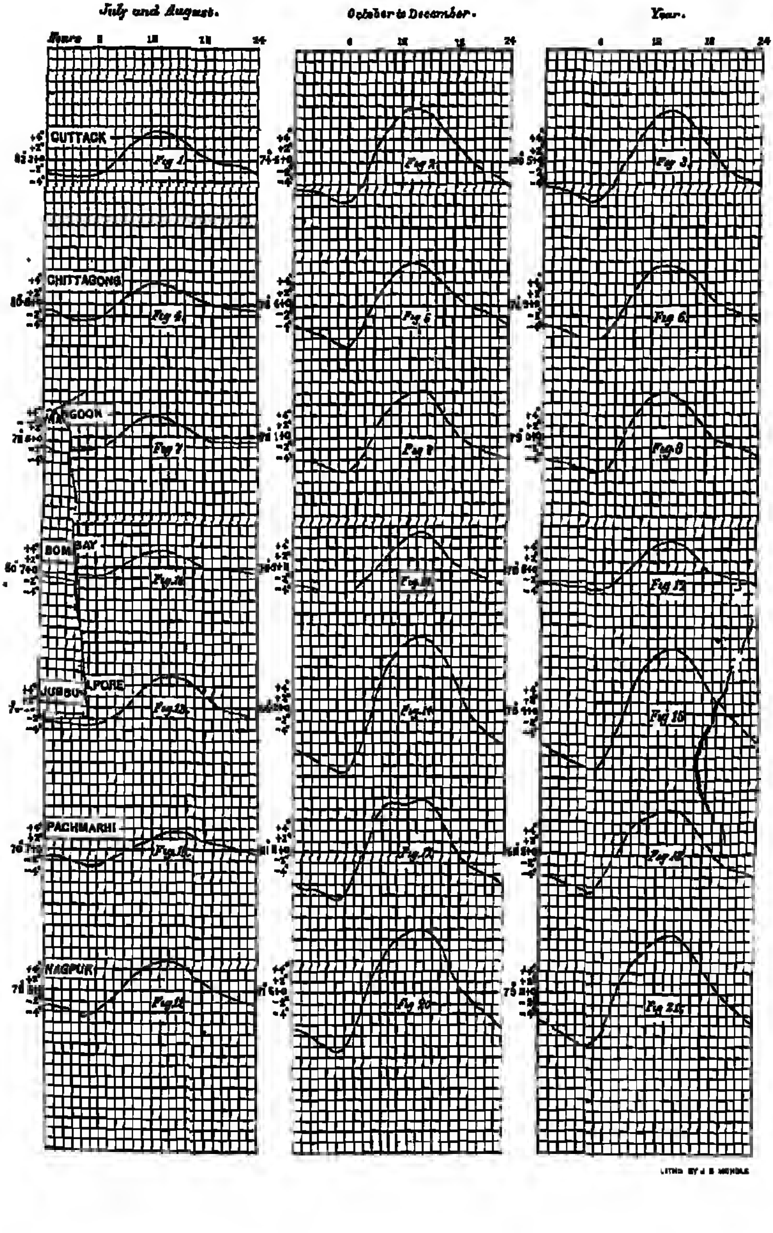
DIURNAL VARIATION OF TEMPERATURE IN



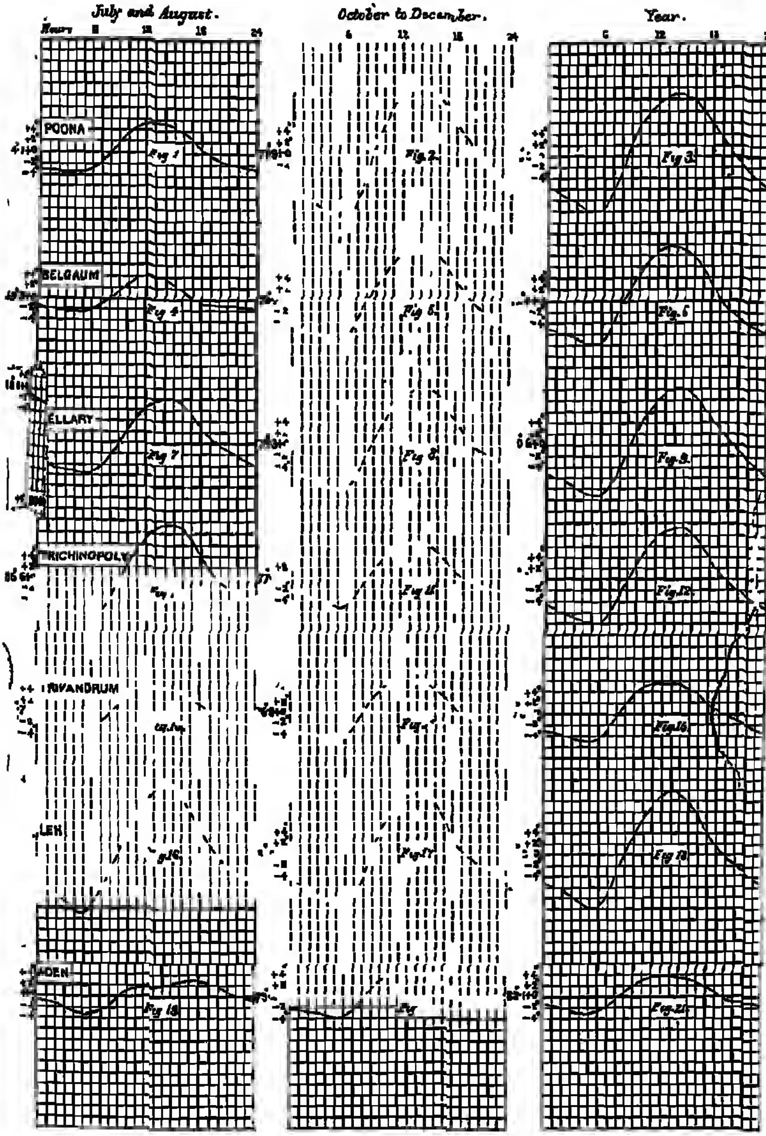
LITHO BY J. H. MUNGLE

DIURNAL VARIATION OF TEMPERATURE IN



LITHO. BY J. B. MONDLE

DIURNAL VARIATION OF TEMPERATURE IN



"If we eliminate the non-periodical agencies from the daily barometric curve, we can represent the latter almost completely by the superposition of two waves of pressure, of which one has a period of an entire day, the other of only half a day. The whole day period comes out much more decidedly on clear than on cloudy days. It has a small amplitude over the ocean, but a very great one over heated land surfaces and in mountain valleys, so that it undoubtedly proves itself, by its striking local peculiarities, to be related to the diurnal range of temperature. The semi-diurnal wave shows itself at all places with a regularity quite unknown among other meteorological phenomena: along each parallel of latitude it comes out with almost uniform amplitude and phase epoch. The latter is (with reference to local time) almost quite constant up to high latitudes, whereas the amplitudes steadily decrease with approach to the Pole. Any relation between this pressure oscillation and the diurnal range of temperature is very obscure.

"Now it is very remarkable that the double daily oscillation is the principal phenomenon. It exhibits the greatest amplitudes, and over equatorial oceans is almost the only one represented.

"It seems therefore certain that the solar diurnal variation of the barometer is due to temperature. Now the diurnal term in the harmonic analysis of the variation of temperature is undoubtedly much larger in all places than the semi-diurnal. It is then very remarkable that the semi-diurnal term of the barometric effect of the variation of temperature should be less, and so much less as it is, than the diurnal. The explanation probably is to be found by considering the oscillations of the atmosphere, as a whole, in the light of the very formulæ which Laplace gave in his *Mécanique Céleste* for the ocean, and which he showed to be also applicable to the atmosphere.

"When thermal influence is substituted for gravitational in the tide generating force reckoned for, and when the modes of oscillation corresponding respectively to the diurnal and semi diurnal terms of the thermal influence are investigated, it will probably be found that the period of free oscillation of the former agrees much less nearly with 24 hours than does that of the latter with 12 hours; and that therefore, with comparatively small magnitudes of the tide-generating force, the resulting tide is greater in the semi-diurnal term than in the diurnal.

"The most important conclusion which we gather from the preceding remarks is, that over the tropical oceans very small temperature oscillations accompany very great pressure oscillations. The diurnal variation of temperature at sea is certainly considerably less than that which results from our equations, because the observations are strongly influenced by the heating of the ship's hull. It is probable that the true semi-amplitude in the open sea is not greater than 0°·3C.

"Dr. M. Margules has undertaken the difficult and laborious work, following out Lord Kelvin's suggestion, of calculating, on the lines laid down by Laplace, the oscillations in the earth's atmosphere as they might be due to its periodical warming.

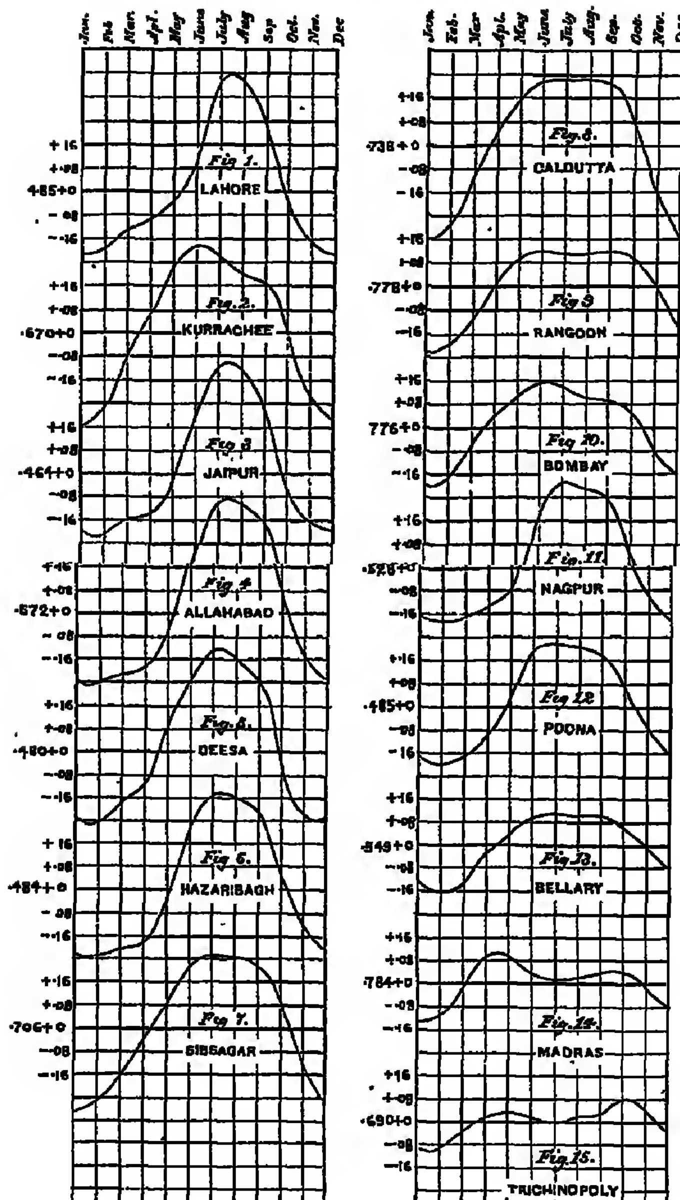
"The calculation is simplest for a shell of air at rest if friction be neglected. The constant oscillations of the air in a spherical shell at rest have been calculated by Lord Rayleigh. Dr. Margules has solved the problem for a rotating shell of air subject to friction, and by this has rendered it possible to apply the results to the explanation of the daily barometric oscillation.

"Dr. Margules shows, in the first of his memoirs on the subject, that the period of free oscillation in a rotating spherical shell of air (of the usual temperature) is nearly 12 hours. If we take for the spherical shell of air the actual rotation of 24 hours, it suffices to assume a mean (absolute) temperature of the atmosphere of 268° (−5°C.), in order that the oscillation thereby produced, and which have only half the duration of the rotation, shall attain a very great amplitude.

"Accordingly, a very small semi-diurnal temperature wave will suffice to produce a very great pressure wave. The phases of both are accordant at temperatures under 268°; in other cases they are opposed. If the calculation leads to values too minute to have any real importance, it certainly follows that much smaller temperature oscillations will suffice to produce semi-diurnal pressure waves of the same magnitude as the diurnal ones.

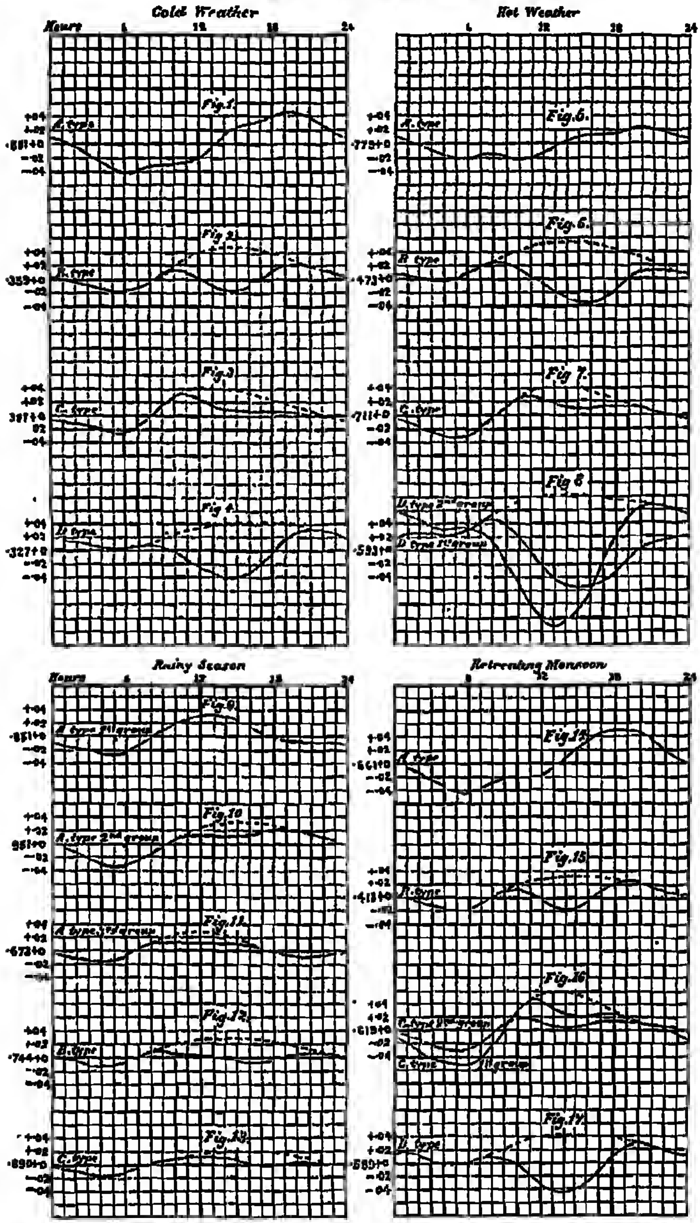
"Margules, in his third paper, investigates the influence of friction on waves which are caused by temperature oscillations or by periodical forces.'

ANNUAL VARIATION OF VAPOUR PRESSURE IN ...



LITHO BY J. N. MUNDLE

DIURNAL VARIATION OF VAPOUR PRESSURE ACCORDING TO TYPES
FOR EACH OF THE FOUR SEASONS



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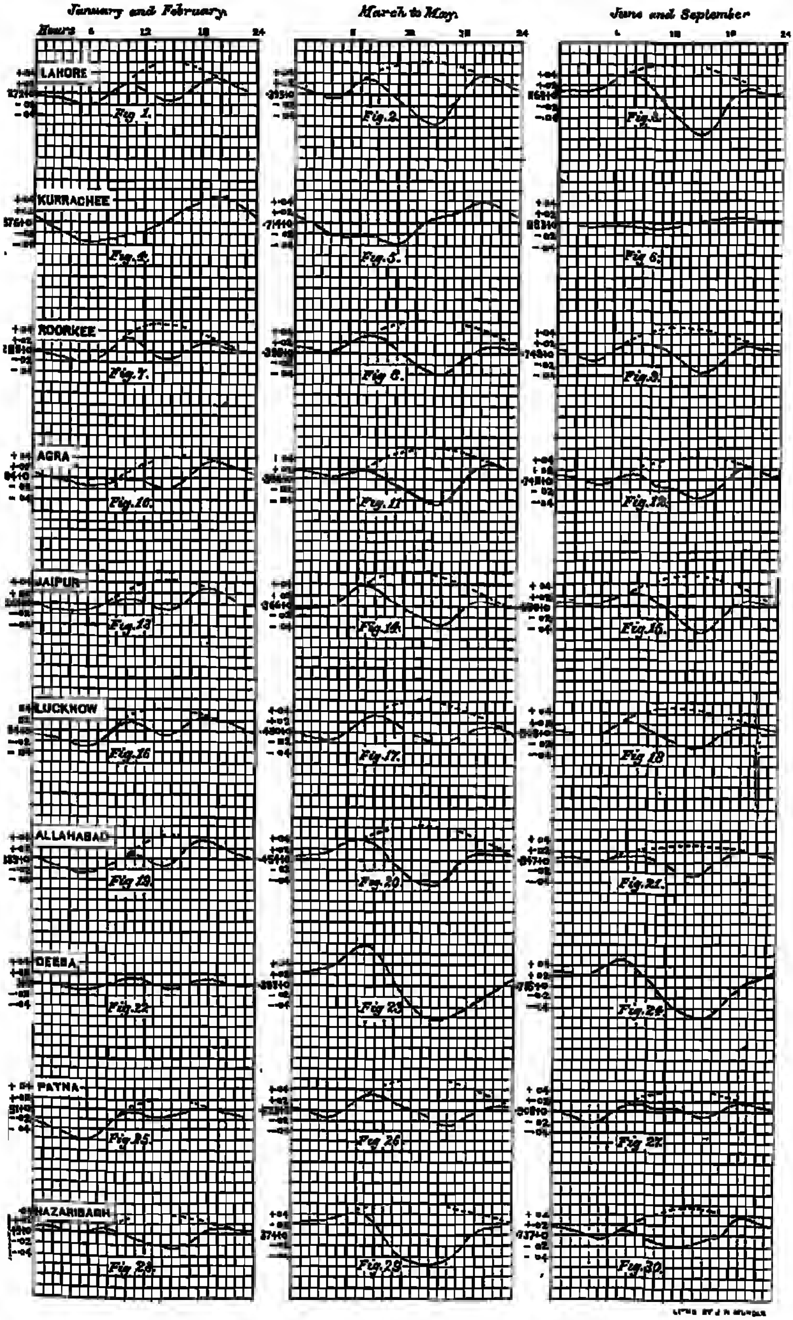

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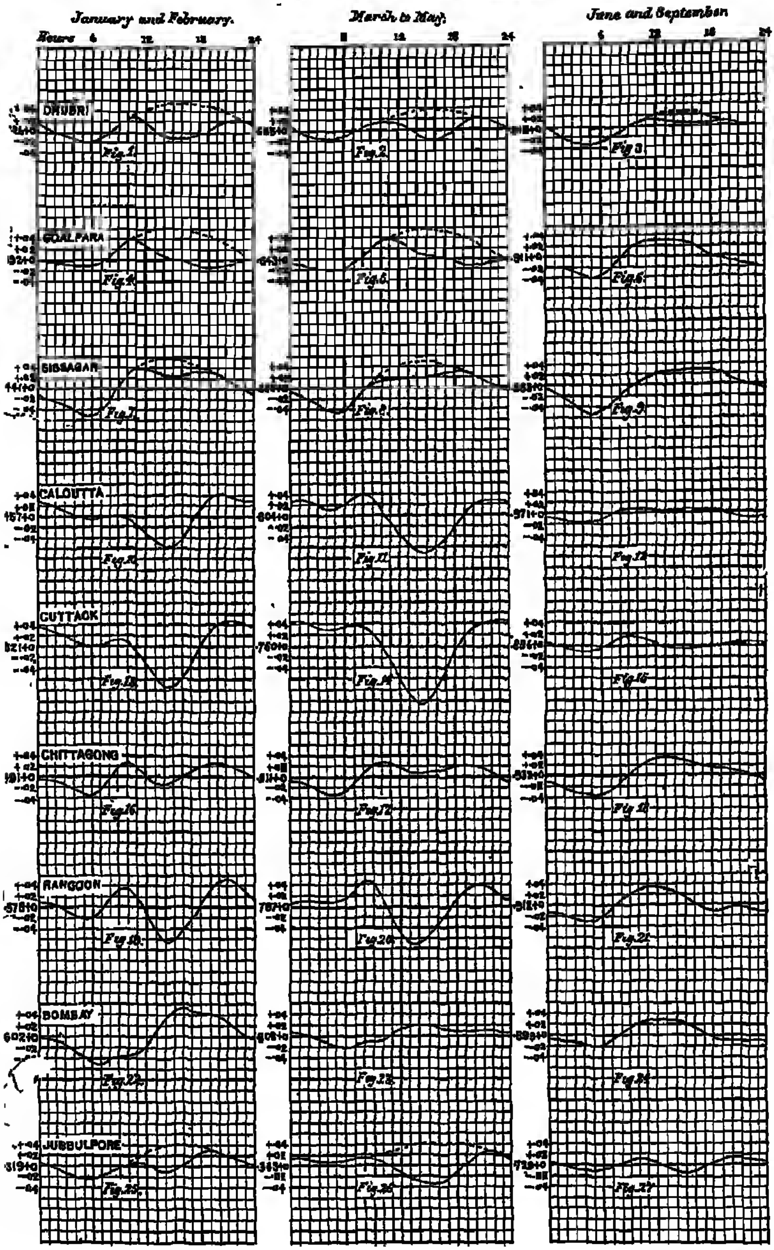

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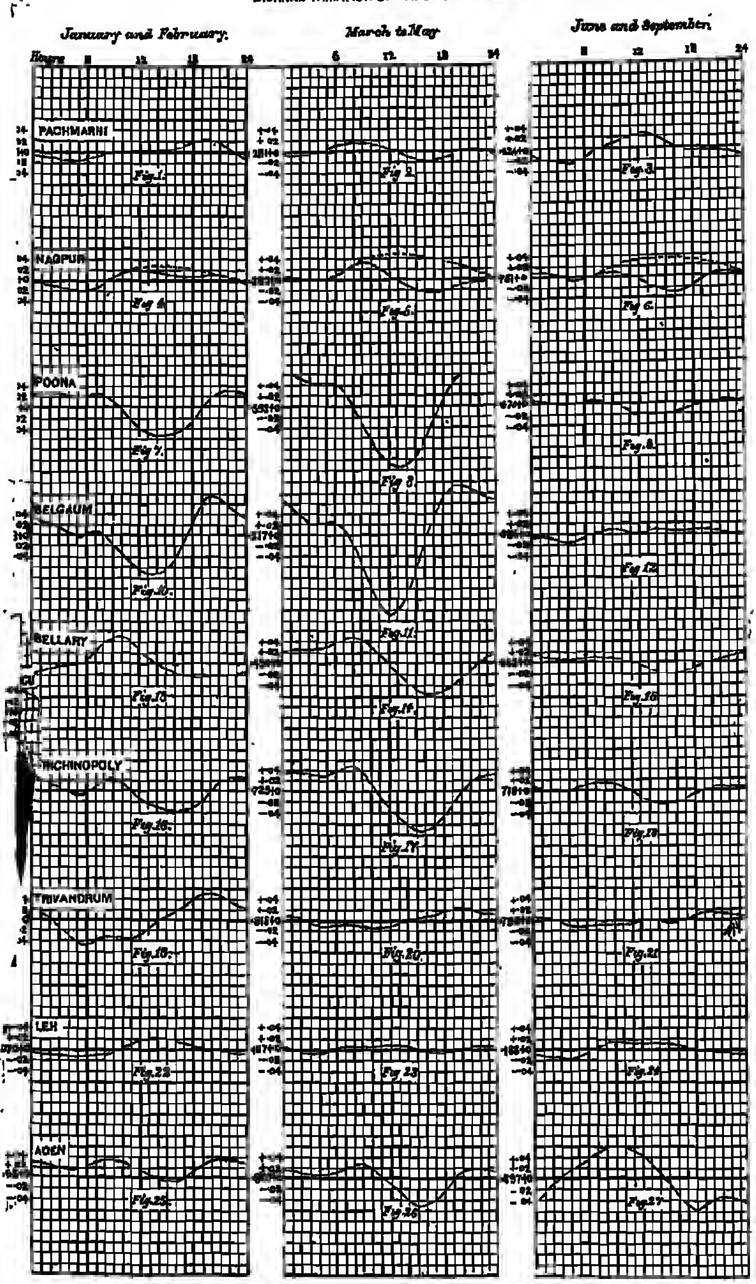
DIURNAL VARIATION OF VAPOUR PRESSURE IN



"It follows from his calculations in that paper, that if we assume in an upper stratum of the atmosphere a regular daily range of temperature to exist, which may be represented by a sum of westward-moving waves of periods of 24, 12 . . . . hours' duration, the diurnal pressure wave at the ground-level comes out small, but the semi-diurnal pressure wave exhibits an amplitude which is very great in comparison with the corresponding temperature wave. If we knew the daily range of temperature in the upper strata, the equations proposed by Dr Margules would lead to a nearly complete solution of the problem of the daily barometric oscillation."

(3) CURTIS.—Curtis has discussed the diurnal variation of the barometer in the British Isles in a paper read before the Royal Meteorological Society in November 1899. The data discussed were the mean values of pressure for the four stations of Kew, Aberdeen, Falmouth and Valencia for each month of the year obtained from hourly observations for a period of 25 years.

The following are the more important conclusions which he obtains from the examination of the data:—

(1) "There does not appear to be any direct connection between the epochs of the critical phases of the pressure oscillation and those of temperature. Thus whilst the epoch of maximum temperature only varies about an hour throughout the year, the epochs of the first maximum and second minimum of pressure,—the two phases of that oscillation which might be supposed to be most directly affected by the maximum of temperature,—range over several hours. Similarly, although both the minimum of temperature and the morning minimum of pressure become earlier as the summer approaches, the change is not equal in the two elements, and it is not possible to directly connect them as cause and effect."

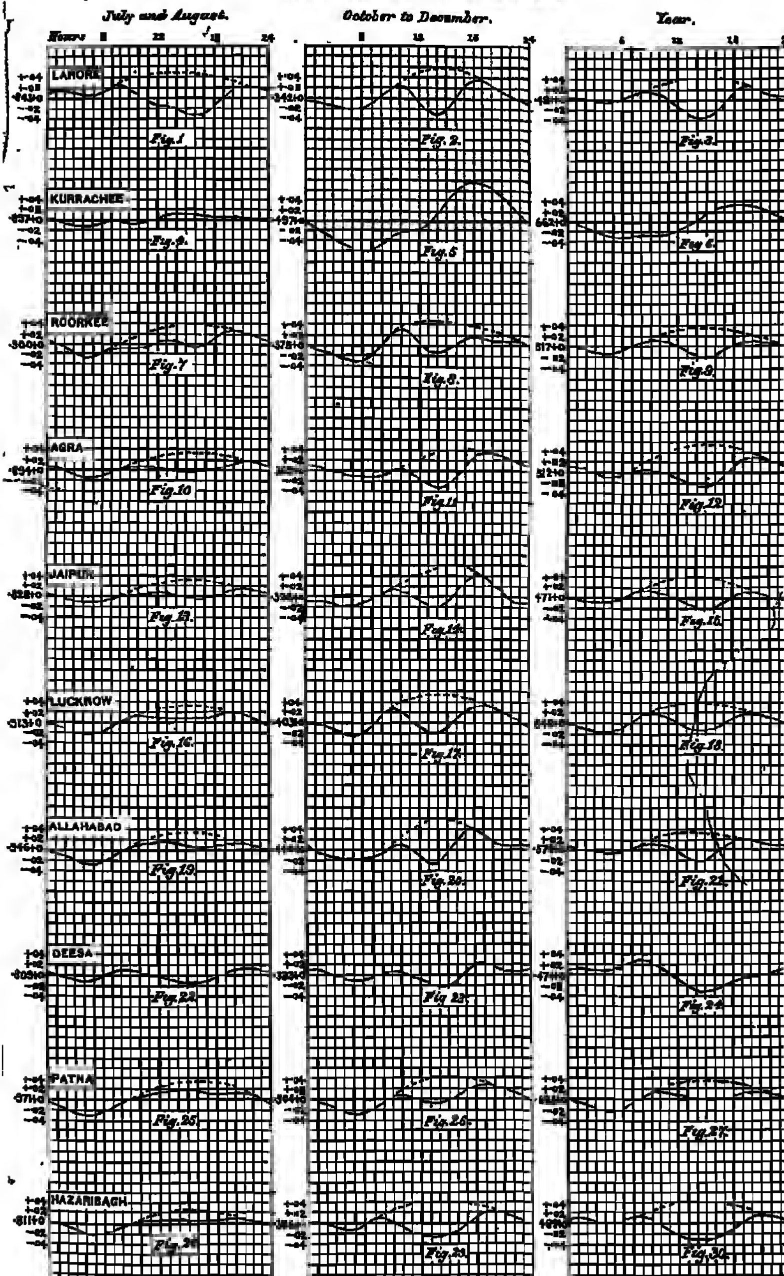
(2) "The changes which occur in the amplitude of the temperature oscillation from month to month, although varying in amount, are yet similar in character at each of the four English stations the observations of which are discussed, whilst the changes which are observed in the pressure oscillation differ at the same places very materially."

(3) "There appears to be no consistent and direct relation between the increase or decrease of vapour tension or of humidity of the air and the diurnal rise or fall of the barometer, for hygrometrical changes which began whilst a given movement of the barometer was in progress are found to continue unchanged till long after that movement has become reversed; and combinations which seem to hold good in certain cases are negatived in others. In short, both as regards their epoch and character it seems impossible to synchronise directly the changes in these different elements or to indicate precisely their relation to each other."

(4) "It appears to be almost certain that in the simple diurnal oscillation of temperature lies the original source, the *primum mobile*, of the more complex daily barometric movement and that its action is by no means always a direct one, that the final result may be brought about through the action of more than one secondary agent is quite possible, but that the aqueous vapour of the atmosphere is one of them hardly admits of doubt."

(5) "The primary cause of the diurnal oscillation of the barometer is solar

DIURNAL VARIATION OF VAPOUR PRESSURE IN



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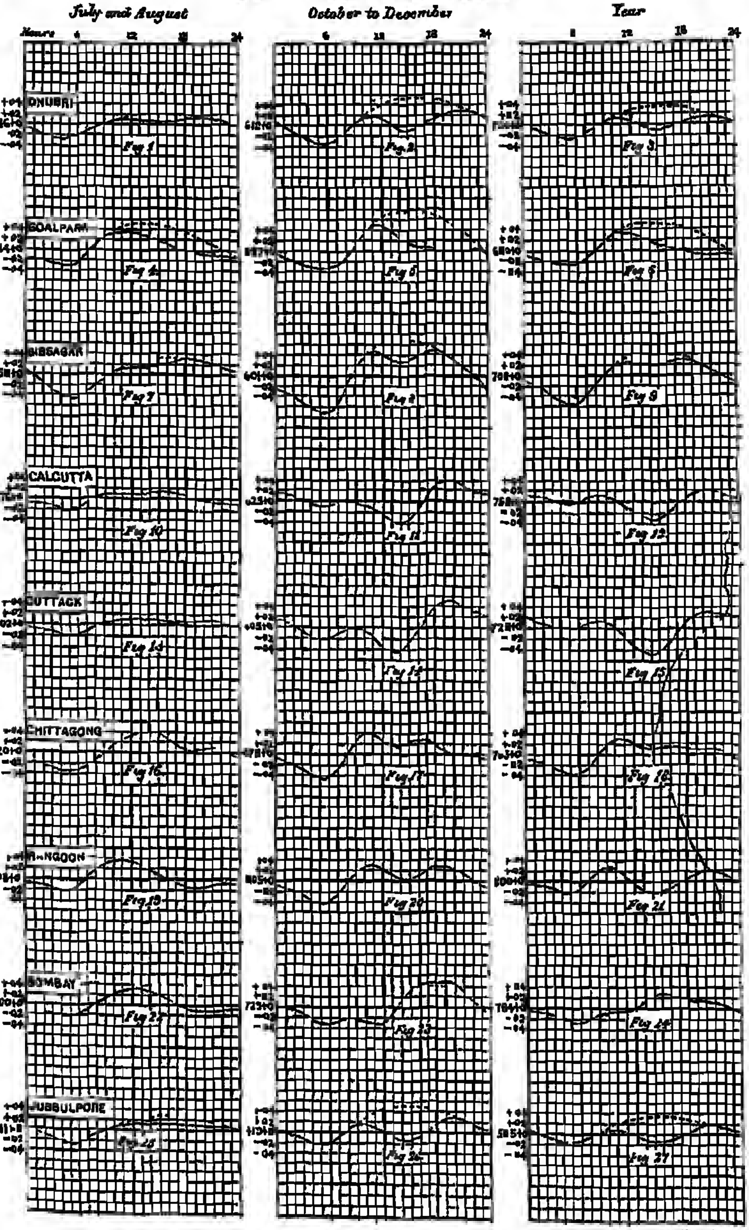
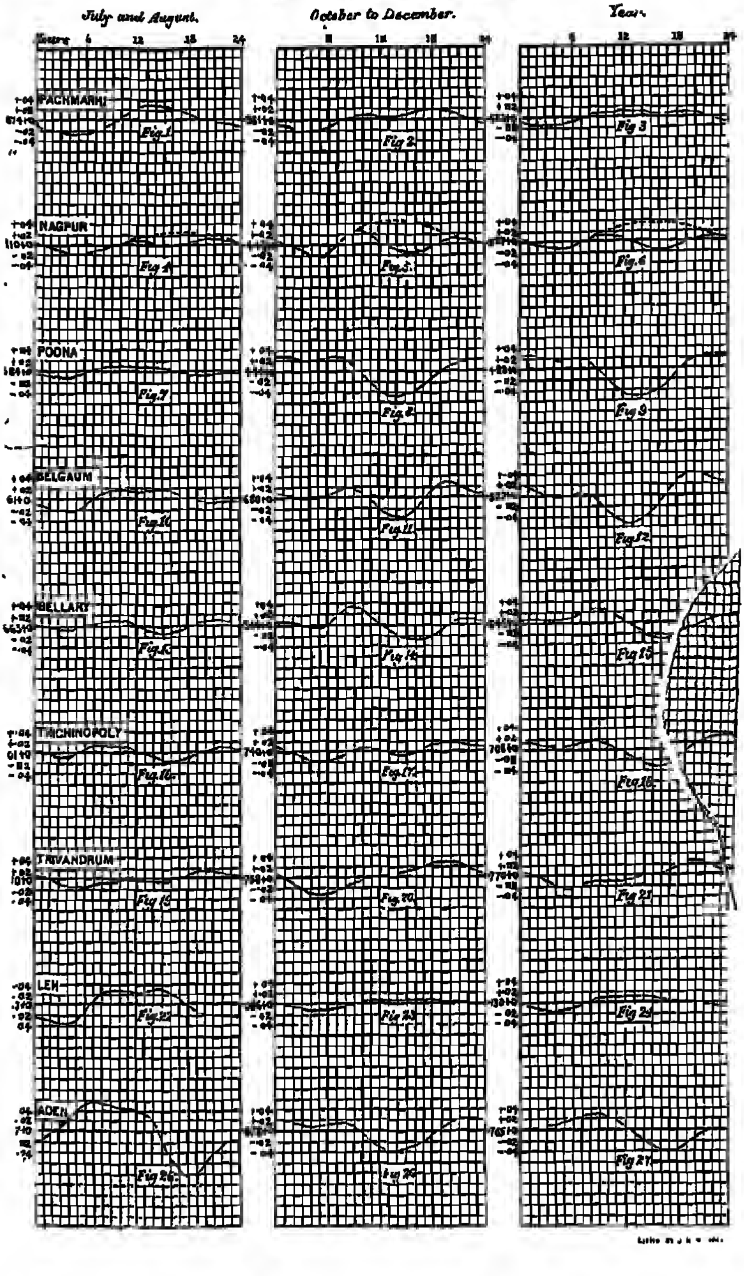
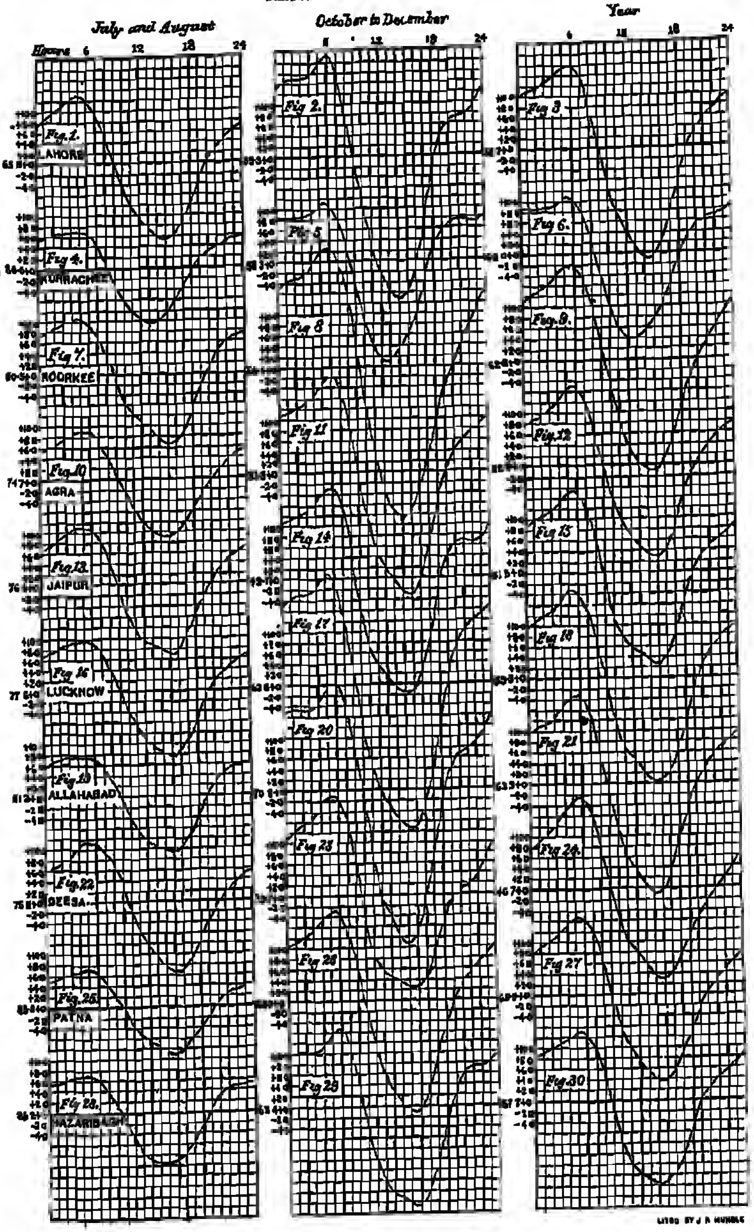


DIURNAL VARIATION OF VAPOUR PRESSURE IN

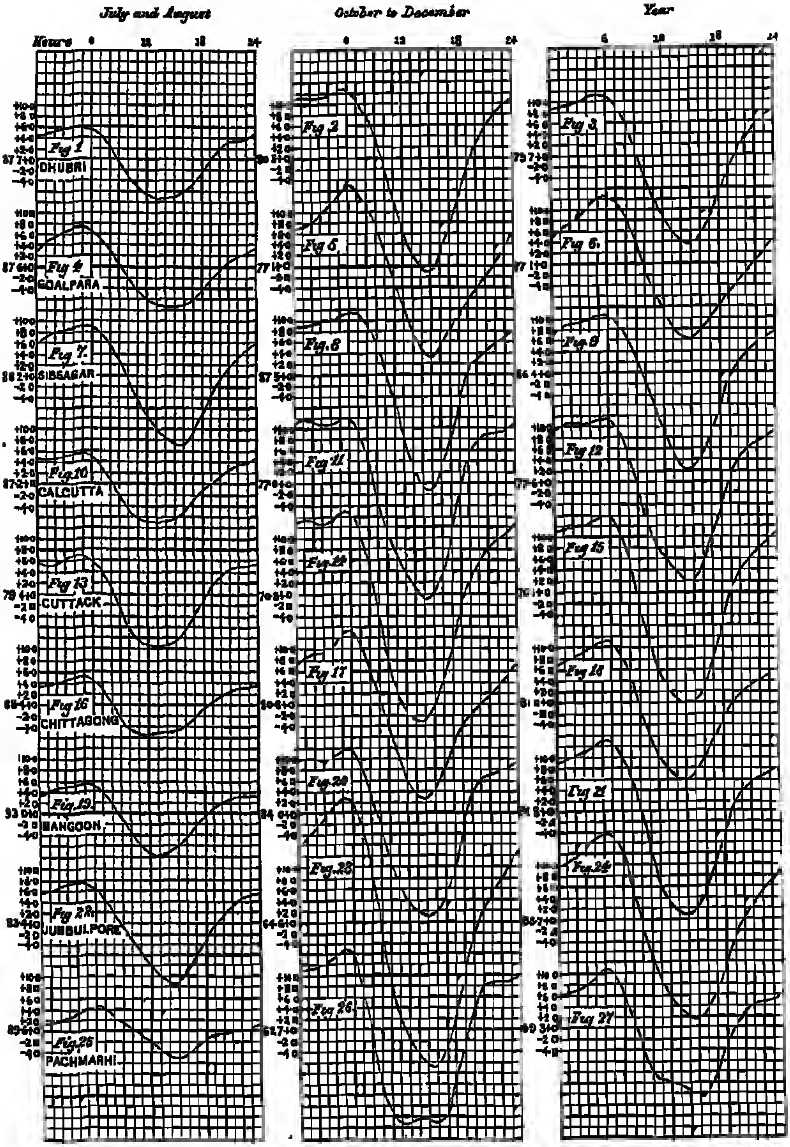


DIURNAL VARIATION OF HUMIDITY IN _



LITHO BY J R HUNDLE

DIURNAL VARIATION OF HUMIDITY IN



LITHO BY J. B. HUMBLE

radiation, operating both directly and indirectly and more particularly upon the lower strata of the atmosphere."

(6) "The amplitude of the oscillation is chiefly determined by the temperature and also by the amount of the diurnal range of temperature of the lower strata of the atmosphere."

(7) "Aqueous vapour probably plays an important, if somewhat obscure, part in producing the diurnal barometric oscillation and also in bringing about the seasonal changes observed, but in this connection the changes in the elasticity of the vapour have to be considered as subject to modification by changes in the relative humidity of the air and by the effects of evaporation and condensation."

(8) "The relative magnitudes of the different phases of the barometric oscillation, as observed, depend largely upon the geographical position and physical surroundings of the place of observation in so far as these are capable of modifying its temperature conditions, and especially the relative distribution of temperature over the regions immediately surrounding it."

Curtis adds the following remark:—

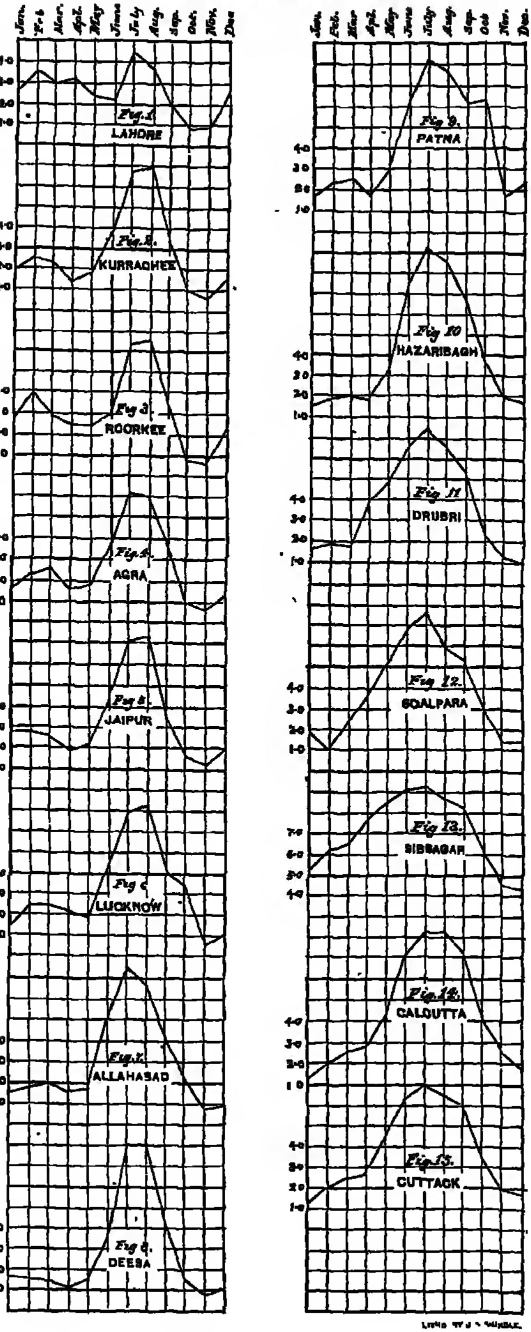
"We have seen that, whatever may be the *primum mobile* of the phenomenon, the temperature conditions near the earth's surface are all-powerful in its further development These very probably act upon the barometer to some extent by varying the tension of the air and of the aqueous vapour the air contains, but for a full explanation of the facts shown to exist there would also seem to be required some system of atmospheric currents, capable of affecting the mass of the atmosphere above the place of observation; and it is not difficult to understand how such currents should result from these same conditions of surface temperature."

Preliminary observations.—All meteorologists are agreed on the primary fact that the diurnal oscillation of the air pressure is a periodic change related to, and determined by, certain actions connected with the apparent diurnal movement of the sun. The maximum and minimum phases of this periodic change invariably occur at the same definite periods of the day and these phases are transmitted from east to west over the earth's surface (more especially within the tropics where the change is most marked and regular in its occurrence) with the velocity of the sun's apparent diurnal movement relative to the earth.

Meteorologists are also agreed that this periodic change of movement is almost certainly due to the daily heating of the atmosphere by the varying solar action. Buchan, for example, states that the barometric tides are undoubtedly generated by solar and terrestrial radiation in the regions in which they occur, and Curtis, that the primary cause of the diurnal oscillation of the barometer is solar radiation operating both directly and indirectly and more particularly upon the lower strata of the atmosphere.

The primary effect of the solar radiation is to heat any absorbing medium through which it passes or any surface upon which it falls. The atmosphere is an absorbing and radiating medium and is hence heated during the day by the absorption of solar radiation and cooled at night by radiation and other processes. The range of temperature of the lowest strata of the atmosphere varies very considerably in India and it decreases rapidly with elevation, and is probably almost evanescent at an elevation of 5,000 feet and upwards. In the dry season the diurnal range of temperature is sometimes as much as 40° F. in the interior of Northern India. If there were absolutely

ANNUAL VARIATION OF CLOUD IN



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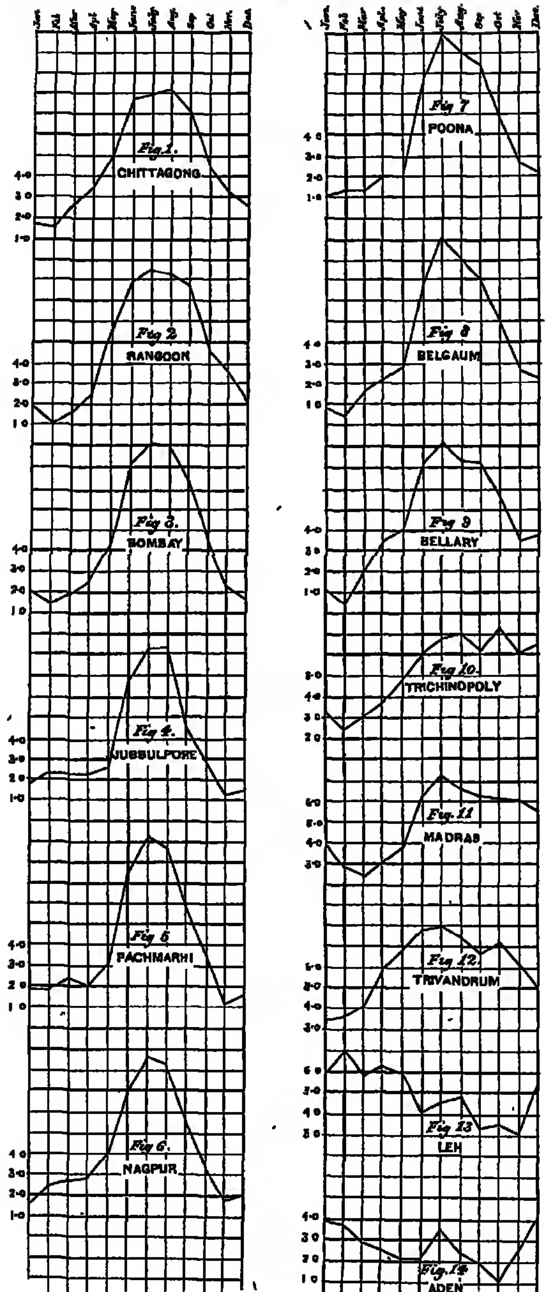
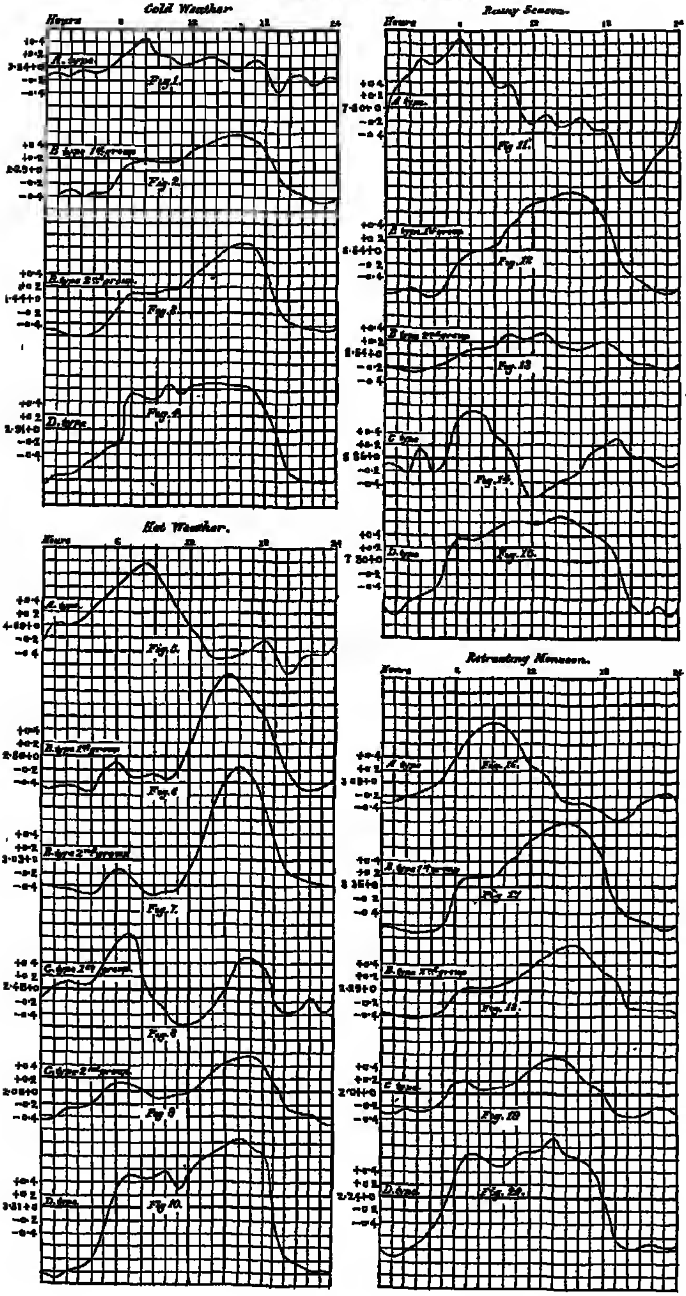


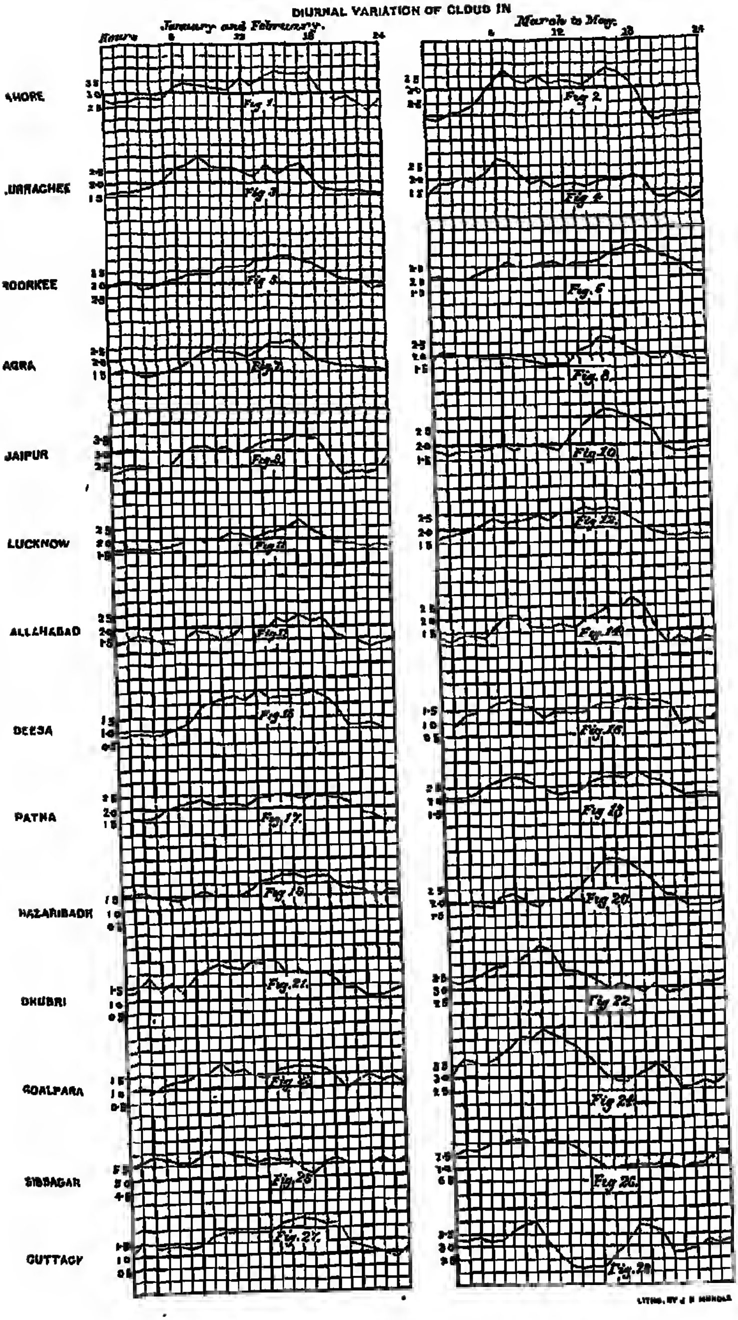
LITHO BY J. H. GRIMBLE

DIURNAL VARIATION OF CLOUD ACCORDING TO TYPES
FOR EACH OF THE FOUR SEASONS

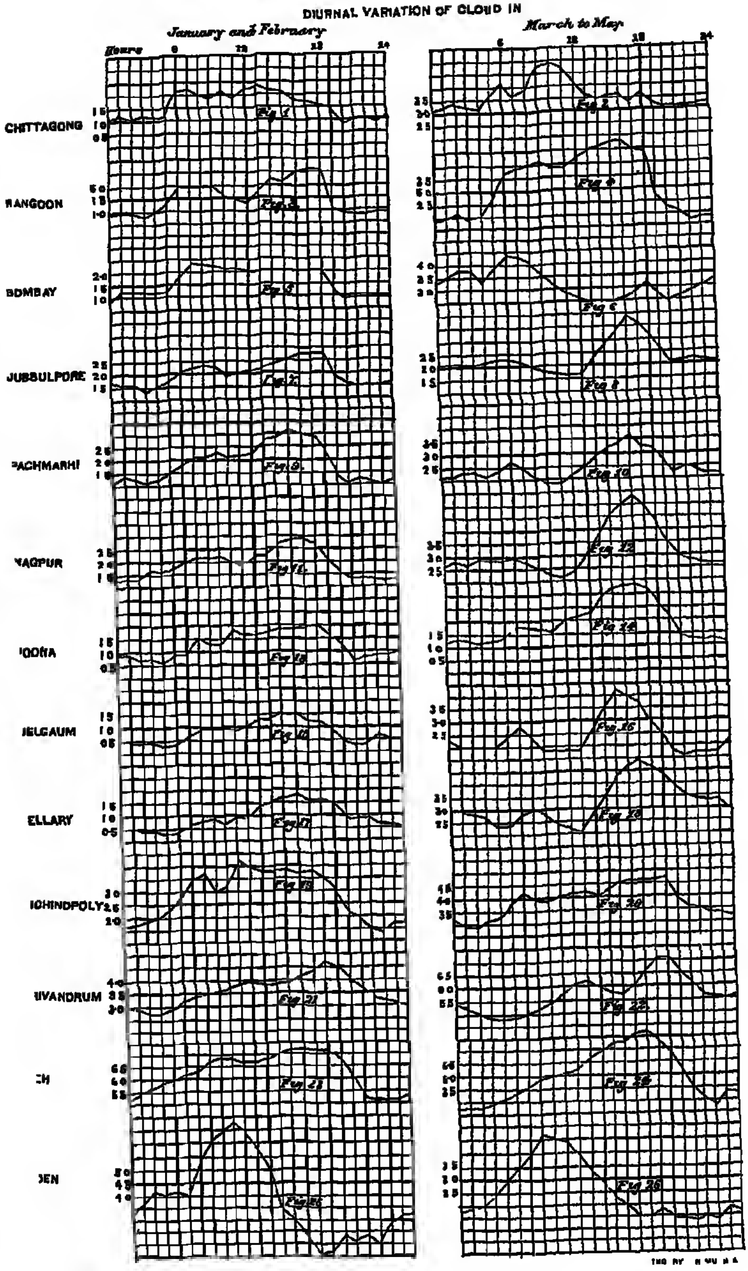


LITHO BY J H MURELL.

DIURNAL VARIATION OF CLOUD IN



DIURNAL VARIATION OF CLOUD IN



no movement of any kind of the atmosphere, an increase of temperature of that amount at any point of the atmosphere in the lowest stratum at the sea-level would be accompanied with or produce an increase of pressure of approximately $2\frac{1}{2}$ inches (*e.g.*, from 30 inches to 32·5 inches) and a corresponding decrease of temperature during the evening and night hours would give rise to an equal decrease of pressure. This diurnal variation of temperature of 40°F would hence, under the assumed conditions, cause a diurnal range or variation of pressure of $2\frac{1}{2}$ inches, the maximum and minimum phases agreeing with the corresponding phases of temperature.

No such large increase or decrease of pressure occurs, and in fact during the greater part of the 24 hours the actual pressure changes are opposite in character to those which would occur with the given temperature changes or solar action if there were no movement of the atmosphere. This inversion of the primary temperature effect is due solely to the air movement set up by the temperature changes. The study of the diurnal movement and changes of movement of the atmosphere is hence essential to progress in the study of the phenomena and causes of the diurnal oscillation. Cleveland Abbe justly remarks that any explanation of the diurnal variation of the barometer that is not deduced from hydrodynamic considerations is of questionable value.

The atmosphere is generally assumed to be of constant mass. It possesses energy, potential and kinetic, the sum of which due to transfer by radiation and other processes is in a state of continuous slight variation. The potential energy per unit volume is proportional to the rate of pressure in that unit volume. In addition to the continuous variation of the total amount of the atmospheric energy there is also a continuous change of the energy from the potential to the kinetic stage and *vice versâ*. The relations between these changes have been hitherto indirectly ascertained, chiefly by means of formulæ or statements in which pressure is assumed as the independent element or variable and the velocity of the air movement as the variable element. The formulæ give definite relations at any given instant, but as they omit the time variable, they do not allow the concurrent changes in the variable with time to be worked out. Hence explanations of pressure phenomena are in many cases as yet purely verbal and are not based on exact mathematical reasoning.

It is shown in mathemetical treatises on hydrostatics that the pressure or rate of pressure at any point in the open atmosphere in contact with the earth assumed to be at rest is equal to the weight of the superincumbent atmosphere.

Any change of pressure under these conditions would hence be due solely to increase or decrease of mass of air over the given point.

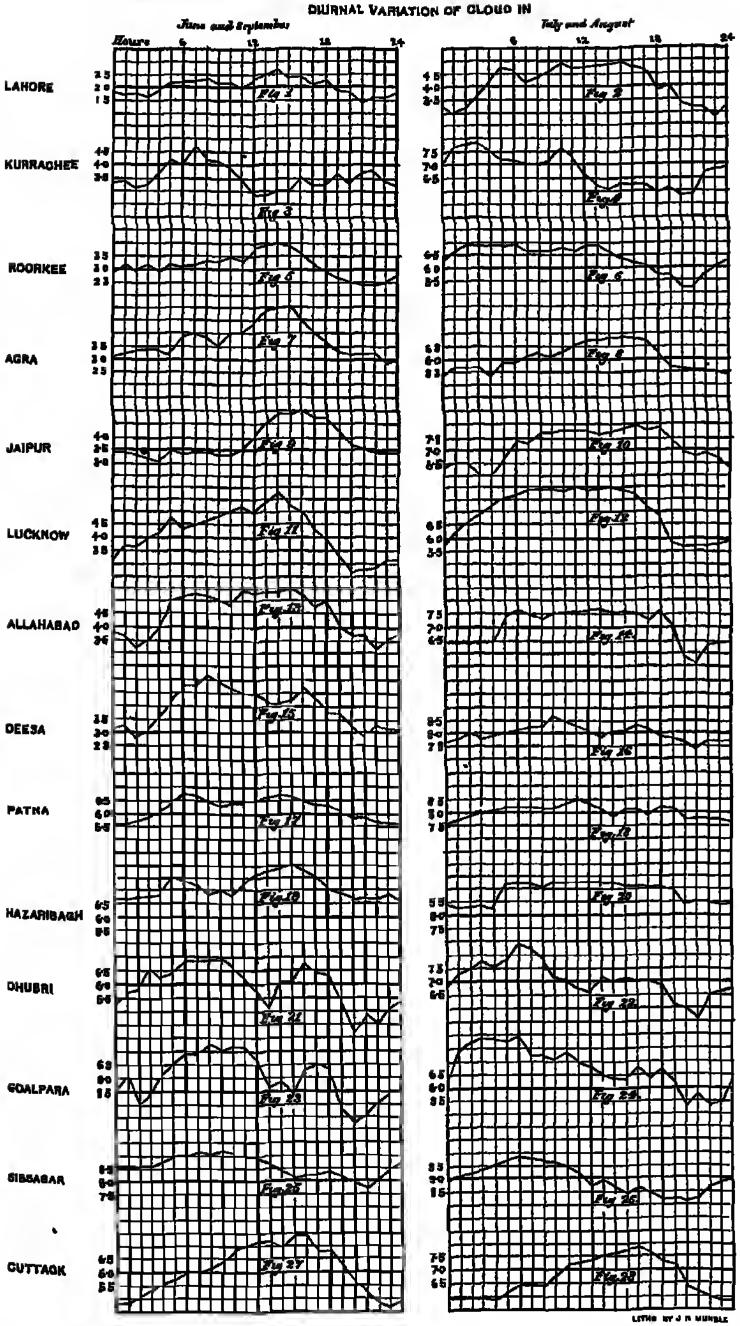
Pressure at any point of the atmosphere assumed to be in mass equilibrium can also be expressed as a function of two variables, *viz.*, temperature and density, by the formula—

$$P = k\rho\ (1+\alpha t).$$

where k is a constant depending upon the mass of the atmosphere.

Meteorologists apparently generally assume that what is true for pressure in a frictionless or non-viscous atmosphere in equilibrium is true (at least very approximately) in the case of our actual atmosphere, *viz*, that the rate of pressure of the atmosphere at the earth's surface is equal to the weight of the superincumbent atmosphere per unit of surface, and hence that the variations of air pressure at any point near the earth's surface are due to variations in the mass or weight of air per unit surface above that point (*vide* Hann's Meteorology, page 162, and Davis's Elementary Meteorology, pages 87, 92, etc.).

DIURNAL VARIATION OF CLOUD IN



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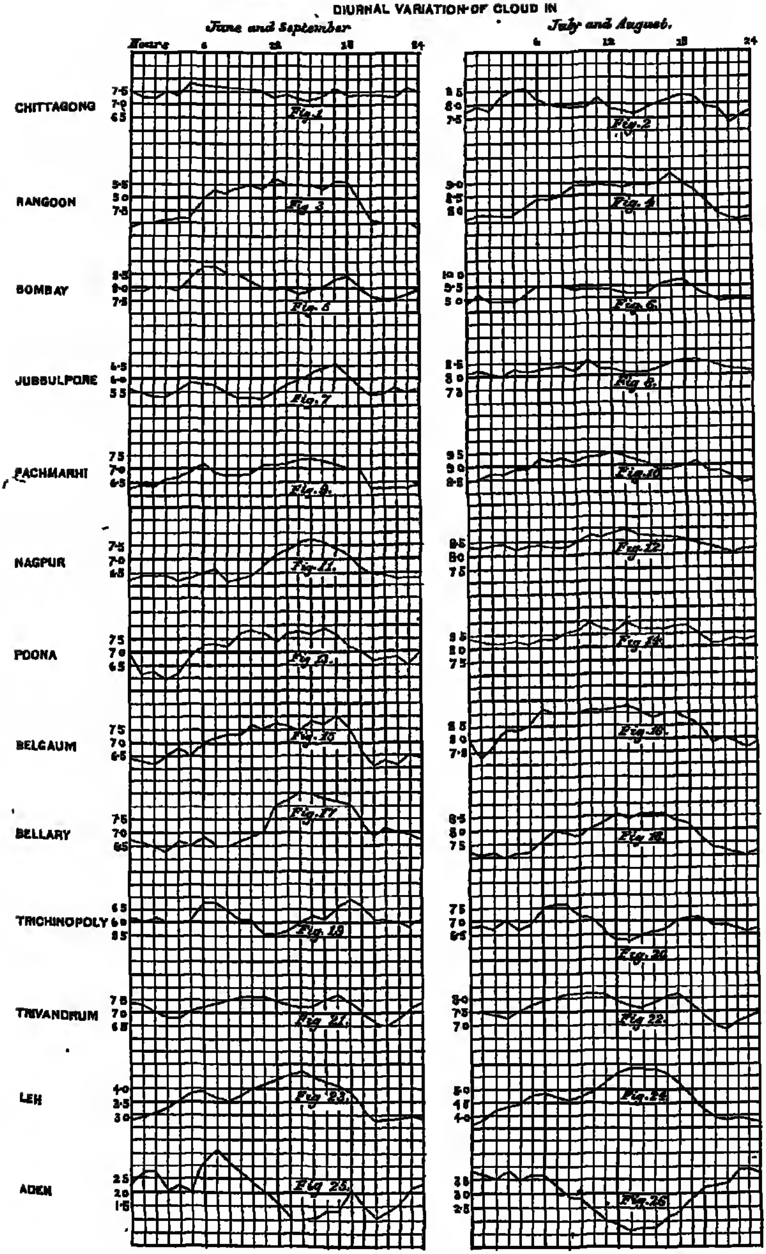

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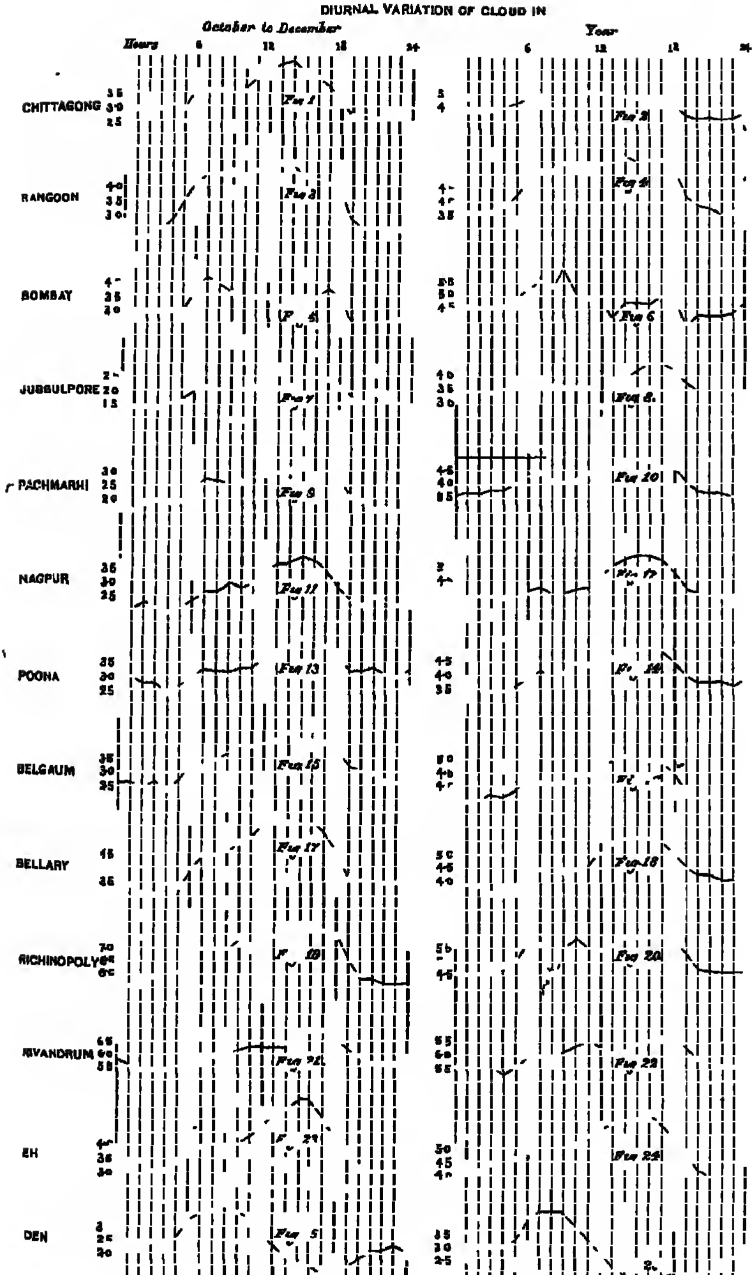

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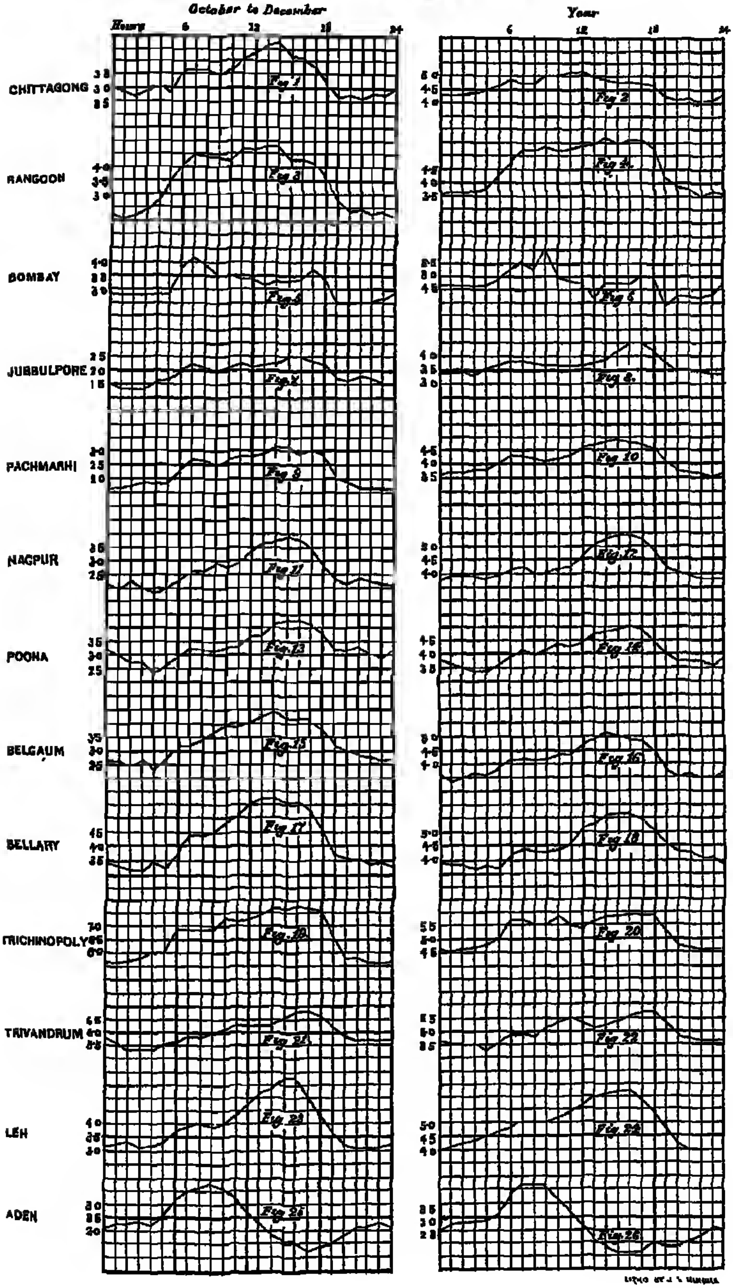
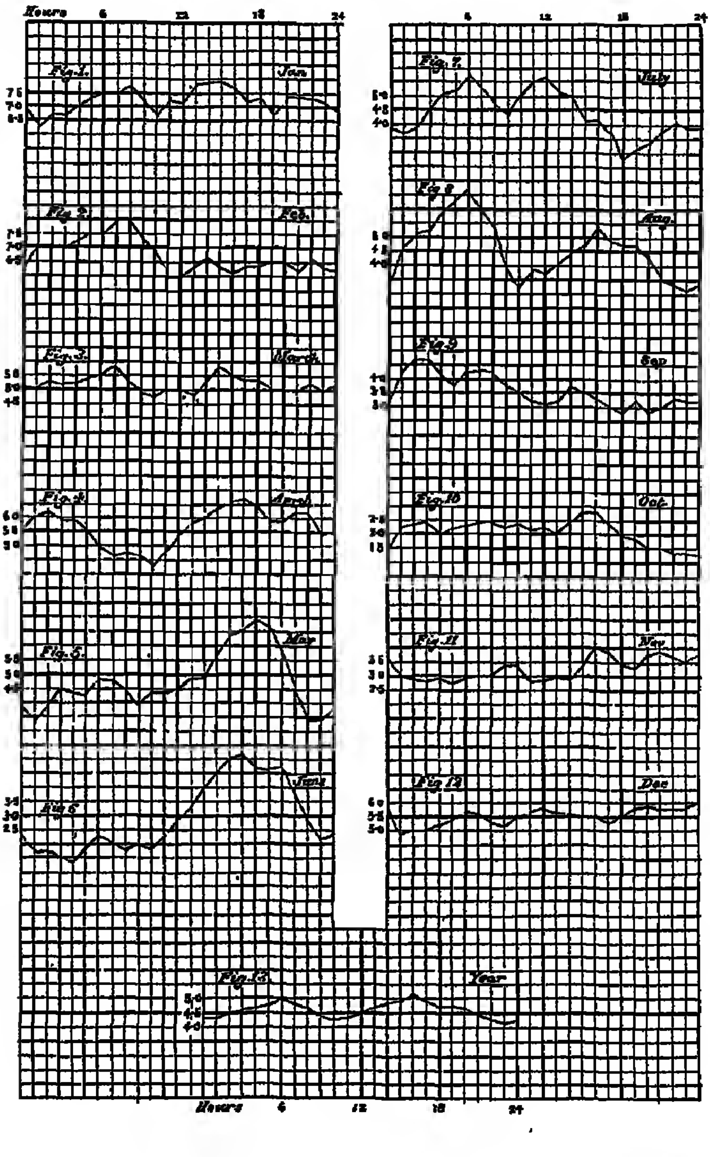


LITHO BY J. S. HARRIS

DIURNAL VARIATION OF CLOUD AT SRINAGAR (Kashmir).



LITHO. BY J. H. MORRIS.

Changes of pressure in the atmosphere are, in the first place, a temperature effect, whether they be due to absorption of solar radiation, condensation of aqueous vapour, etc. Any change of pressure not common to the whole mass is followed by movement of some kind the result of which tends towards the establishment of equilibrium It is generally assumed that the pressure law in the atmosphere, in its actual state of motion, is the same as if it were at rest or in equilibrium

Assuming the principle referred to above, it will be seen that any general movement of expansion or contraction (unaccompanied by horizontal movements) will produce no change of pressure at the earth's surface (neglecting the very slight change of gravity at the varying distances of the centre of gravity of the mass in motion). It may, however, be noted that expansional or contractional movement on the large scale never continues without horizontal movements, in which case the pressure changes are such as occur in ordinary circulatory movements

In this class of air movement, *i e* circulatory motion, there is upward motion or uptake over a more or less considerable area, a horizontal movement in the lower strata towards the area of uptake an outer movement from that area in the higher strata and a general and perhaps irregular downflow at some considerable distance from the seat or area of upflow The whole movement is undoubtedly more irregular than is indicated by this statement

If the movement be such that the outflow above from the area of uptake to that of downflow be greater than the inflow in the lower strata to the region of uptake it is clear that pressure will diminish at the earth's surface in the former area and increase in the latter This will continue so long as the actions giving rise to the movement as for example, increasing temperature or condensation of aqueous vapour, more than balance the various resistances to motion The general result of any actions giving rise to air movement of this class, such as actually occur in nature, is to originate and accompany for a shorter or longer period decrease of pressure over one area and increase of pressure over other areas followed by the reverse changes when the actions decrease in amount or alter in character.

These oscillatory pressure changes may be regularly periodic or may be irregular in their period and occurrence They are periodic in the case of the great seasonal variation in India, from high pressure in the cold weather to low pressure in the hot weather and rains, and *vice versâ* These changes undoubtedly accompany a large transfer of air from one hemisphere to the other

The statement or explanation also accounts more or less fully for the pressure changes in areas of depression and of cyclonic storms, for the irregular changes of short period (of three to five days) constantly in operation in India in the dry as well as the wet season and also for those accompanying the prevalence of land and sea breezes on the small or large scale and of mountain and adjacent plains winds In all these cases pressure changes accompany displacement of air masses and are very approximately, if not exactly, measured at any place near the earth's surface by the change in the weight of the superincumbent air mass per unit surface

There are, however, pressure changes which cannot be explained by this principle It is quite possible that in consequence of the action of viscosity pressure may increase in a given mass of the atmosphere (without movement) for some time, although unaccompanied by an increase of mass of the superincumbent atmosphere Such changes

CHARTS SHOWING NORMAL MEAN PRESSURE AND WINDS.

Fig 1

JANUARY

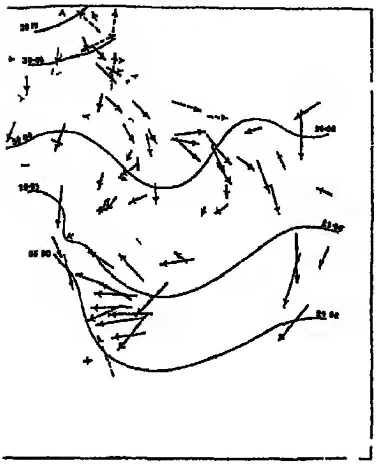


Fig 2

MARCH

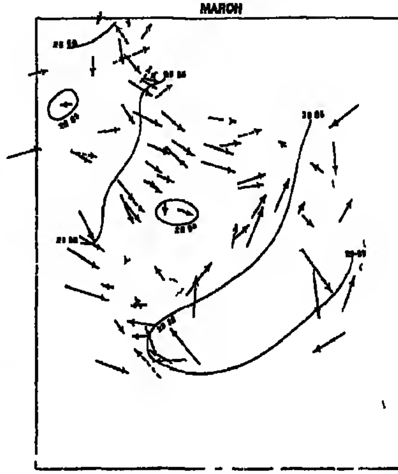


Fig 3

MAY

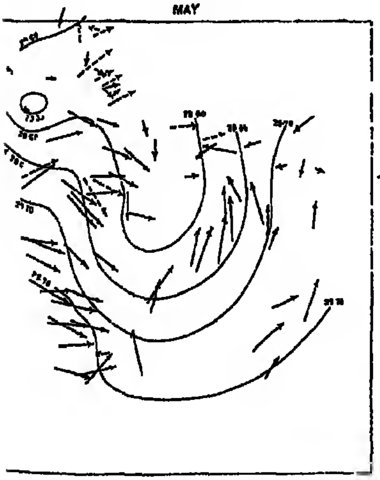
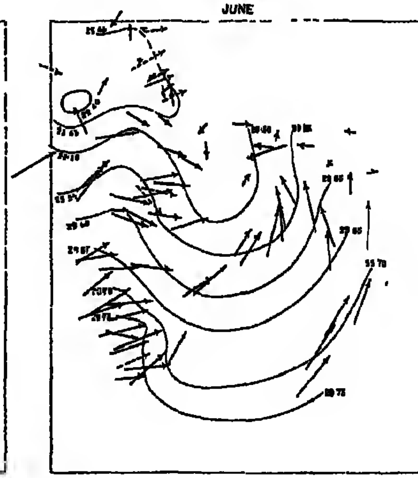


Fig 4

JUNE



CHARTS SHOWING NORMAL MEAN PRESSURE AND WINDS.

Fig. 1.
AUGUST

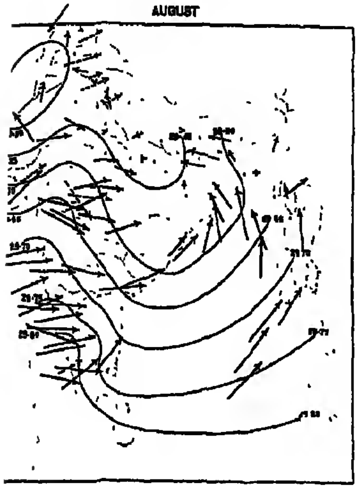


Fig. 2
OCTOBER

Fig. 3
DECEMBER

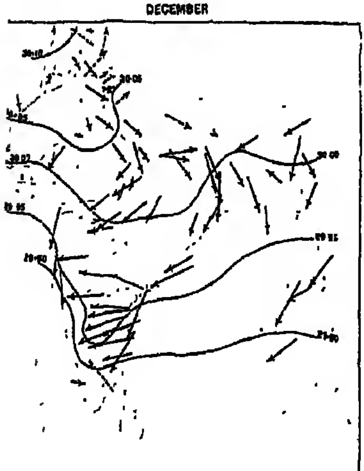
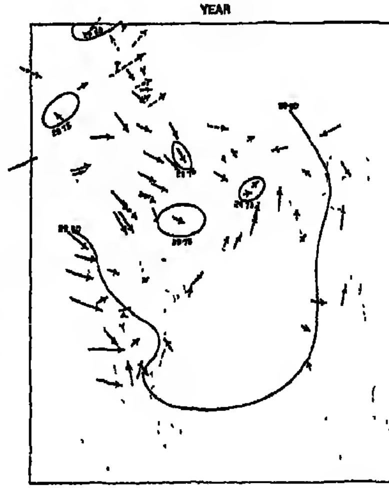


Fig. 4.
YEAR



CHARTS SHOWING NORMAL PRESSURE AND WINDS.

Fig 1

JANUARY 8 A.M

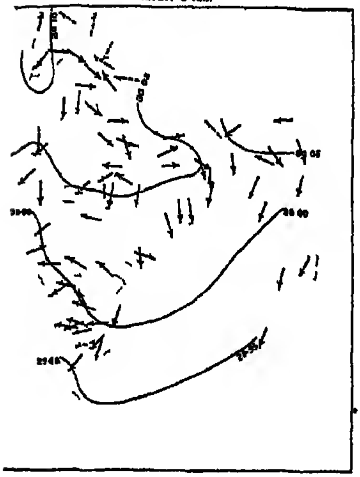


Fig 2

JANUARY 4 P M

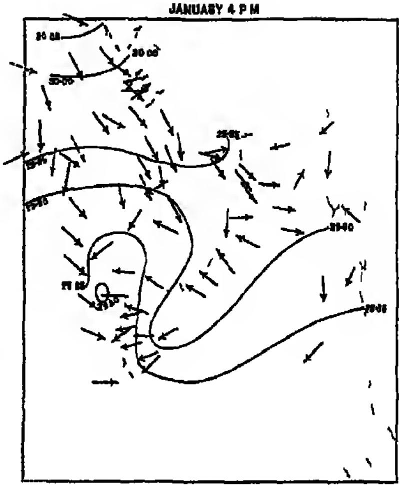


Fig 3

APRIL 8 A.M

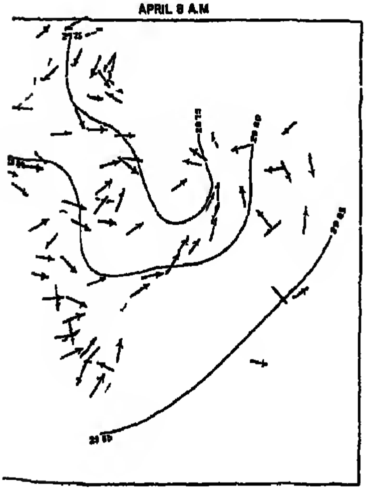
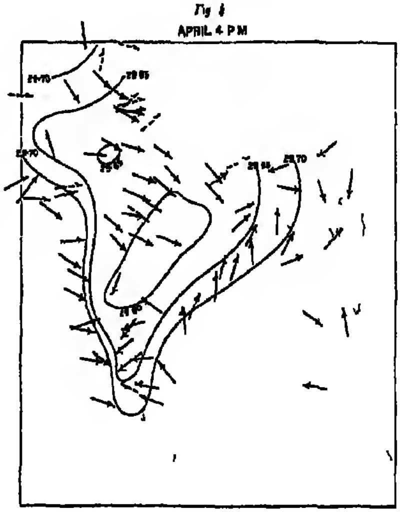


Fig 4

APRIL 4 P M



CHARTS SHOWING NORMAL PRESSURE AND WINDS.

Fig 1
JULY 8 A M.

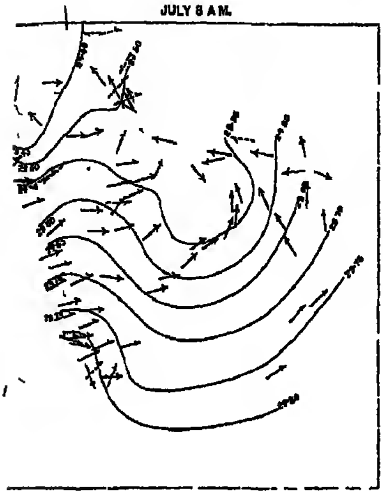


Fig 2.
JULY 4 P M

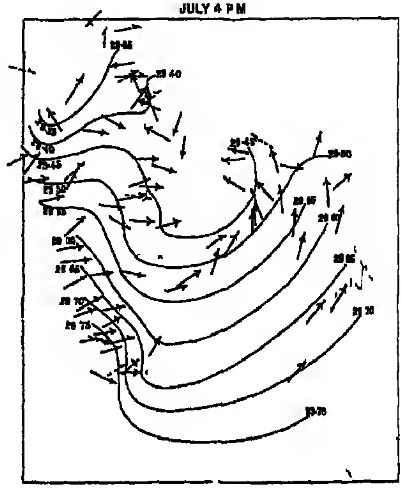


Fig 3
NOVEMBER 8 A.M

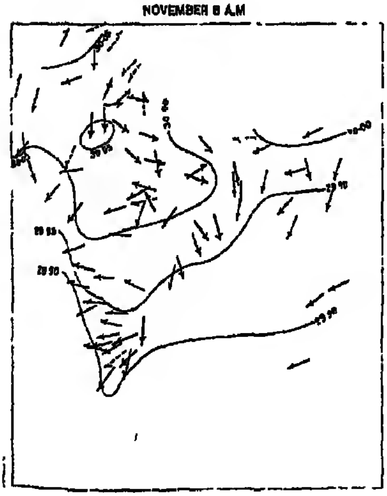
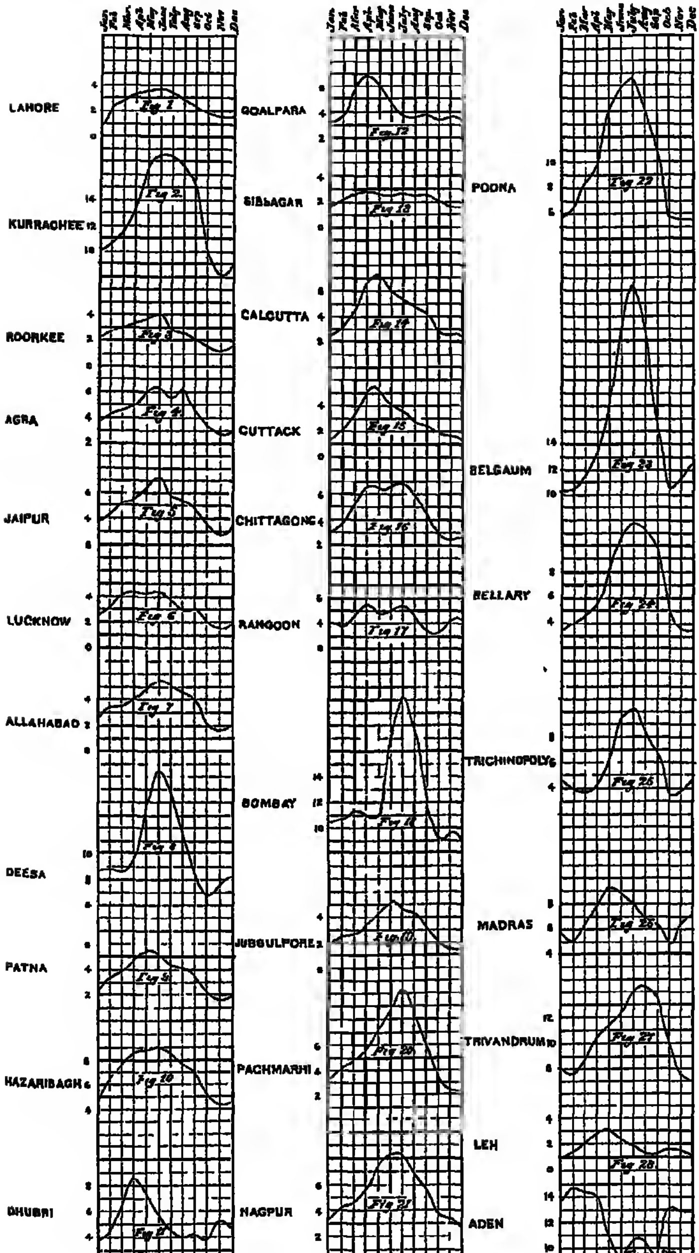


Fig 4
NOVEMBER 4 P M

ANNUAL VARIATION OF WIND VELOCITY IN MILES PER HOUR IN



are apparently of occasional, if not of frequent, occurrence during the hot weather in Upper India, more especially immediately antecedent to the formation of duststorms.

Also the acceleration of ascending and descending currents should theoretically give rise to, or accompany, variations of pressure at the earth's surface independently of changes of the mass of the superincumbent atmosphere above the surface

As Cleveland Abbe states in his "Preparatory studies for deductive methods in storm and weather predictions," the atmospheric pressure at the surface of the earth can only be affected to an inappreciable extent by the inertia of very slowly ascending and descending currents, such as usually occur in the atmosphere.

The following pressure changes of importance (probably of occasional to frequent occurrence in India) also cannot be explained by the general principle, *viz*, (1st) those due to resisting masses, as for example when a massive air current blows directly across a high mountain range, such as the West Ghats, during the hot weather and rains and (2nd) those which accompany the formation and movement of long slender vertical whirls the intensity of which varies from that of the ordinary dust devils in Upper India to that of the tornadoes, of occasional occurrence in Bengal and Assam during the hot weather and of more frequent occurrence in the United States, in which the vertical movement is so violent that the indraught cannot take place sufficiently rapidly, and there is hence a tendency to the establishment of a partial vacuum in the column of rapid uptake

The regular diurnal changes of pressure accompany slow and regular air movements, and hence it may be assumed that very approximately they are at any point of the earth's surface due to corresponding periodic changes in the amount or mass of the superincumbent atmosphere.

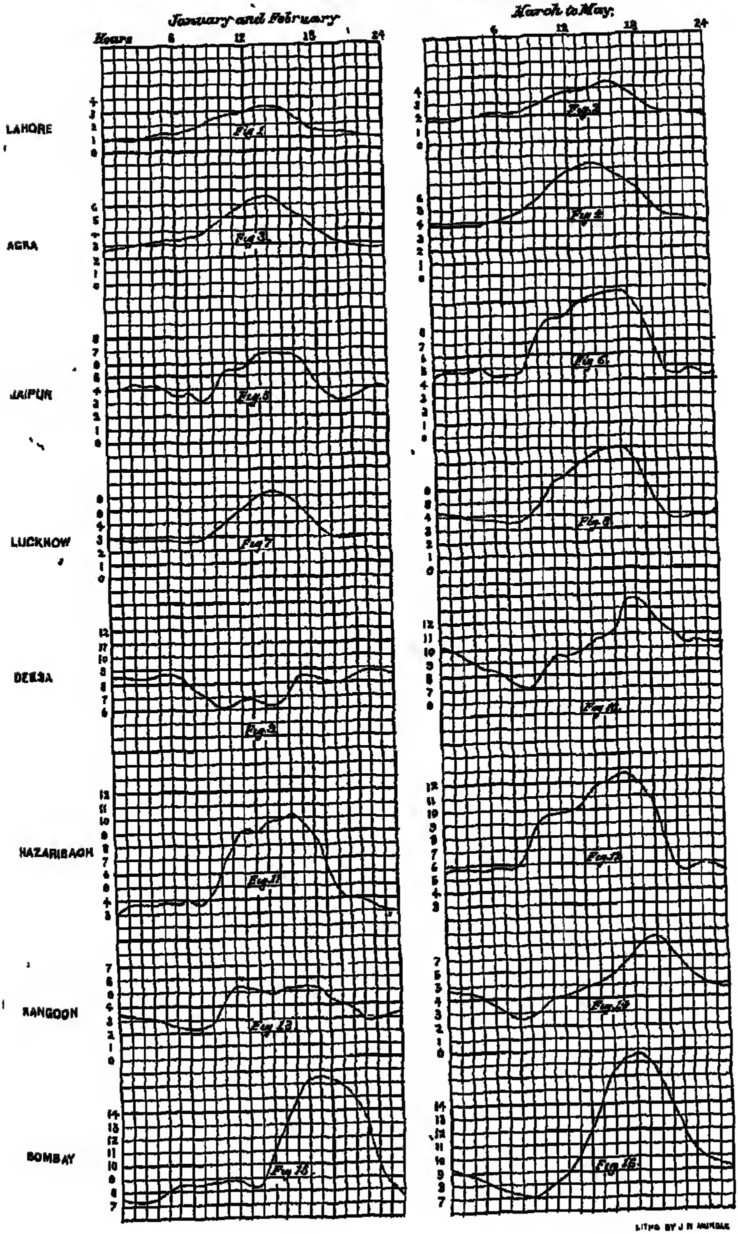
If the view be correct that slow periodic changes of pressure in the open atmosphere at the earth's surface are due to air movement, it follows at once that the rate and character of the change will depend upon that of the variation of the superincumbent air mass There is no evidence that any of the changes accompanying the diurnal oscillation are similar to those giving rise to sound (and hence transmitted at a uniform rate, depending upon elasticity and density of the mass affected).

It appears to be desirable to take up and discuss the problem of the diurnal oscillation of pressure from the "energy" point of view

As already stated, the energy of the atmosphere with which we have to deal is in part kinetic and in part potential The atmosphere as a radiating and absorbing medium absorbs the energy of solar radiation in part in its passage through it The primary effect of this is to increase the temperature and hence also the pressure of the absorbing mass This is, however, speedily followed by the partial or complete transformation of this increase of potential energy into kinetic energy The atmosphere also absorbs in part the energy of terrestrial radiation in its passage outwards into space This absorption of solar and terrestrial radiation occurs throughout the whole mass or depth of the atmosphere and may be described as "mass absorption" On the other hand, the atmosphere as a radiating substance is continually giving out its energy in slight part to the earth but in chief part to space Hence as already stated, there will be a continuous periodic variation in the energy of the atmosphere due to this action, and also a continuous redistribution between its potential and kinetic forms of energy

The energy of the atmosphere is also in a state of continuous periodic variation due

DIURNAL VARIATION OF WIND VELOCITY IN MILES PER HOUR IN



LITHO BY J R HUNDLE

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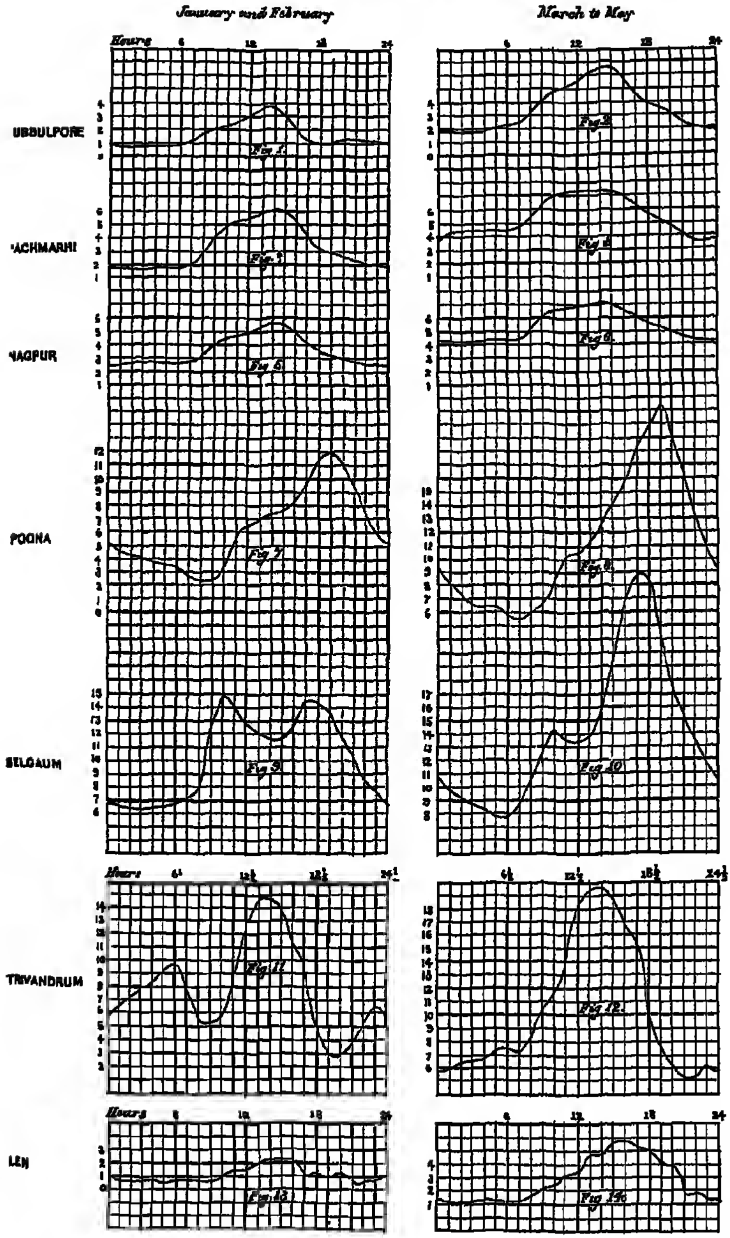

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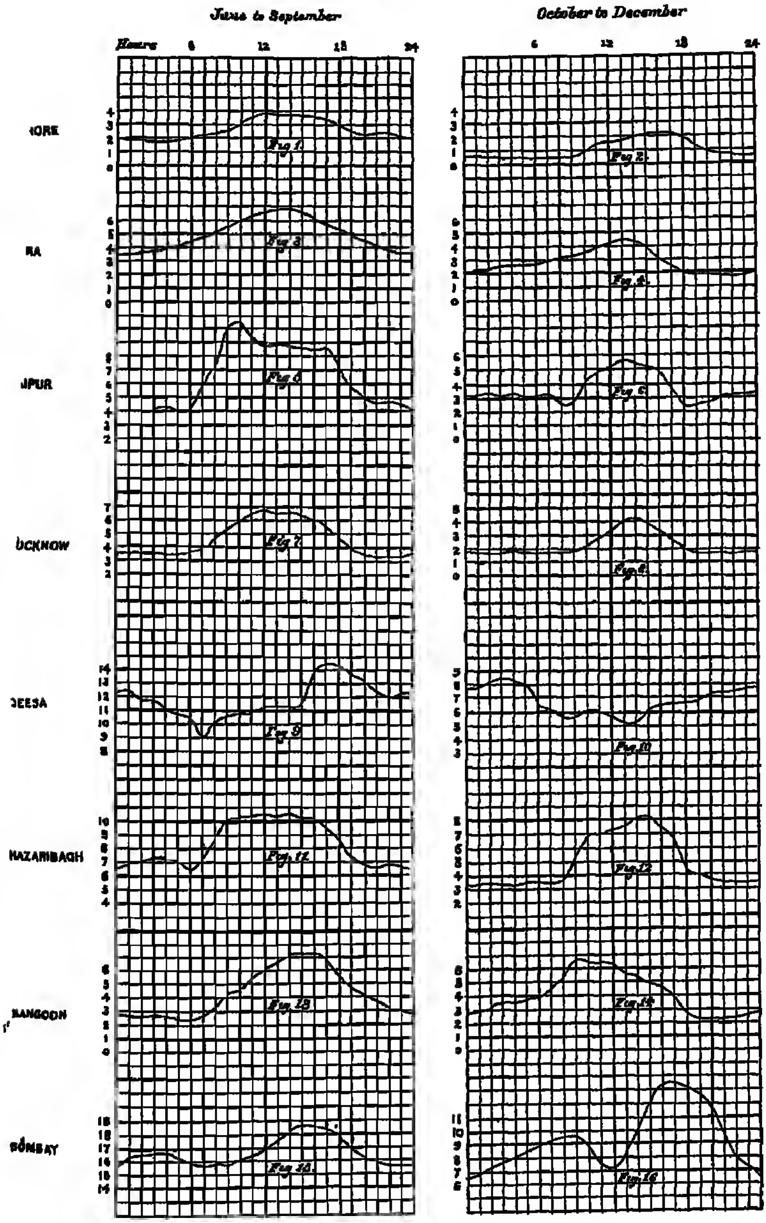

LITHO BY J.N MENDIS

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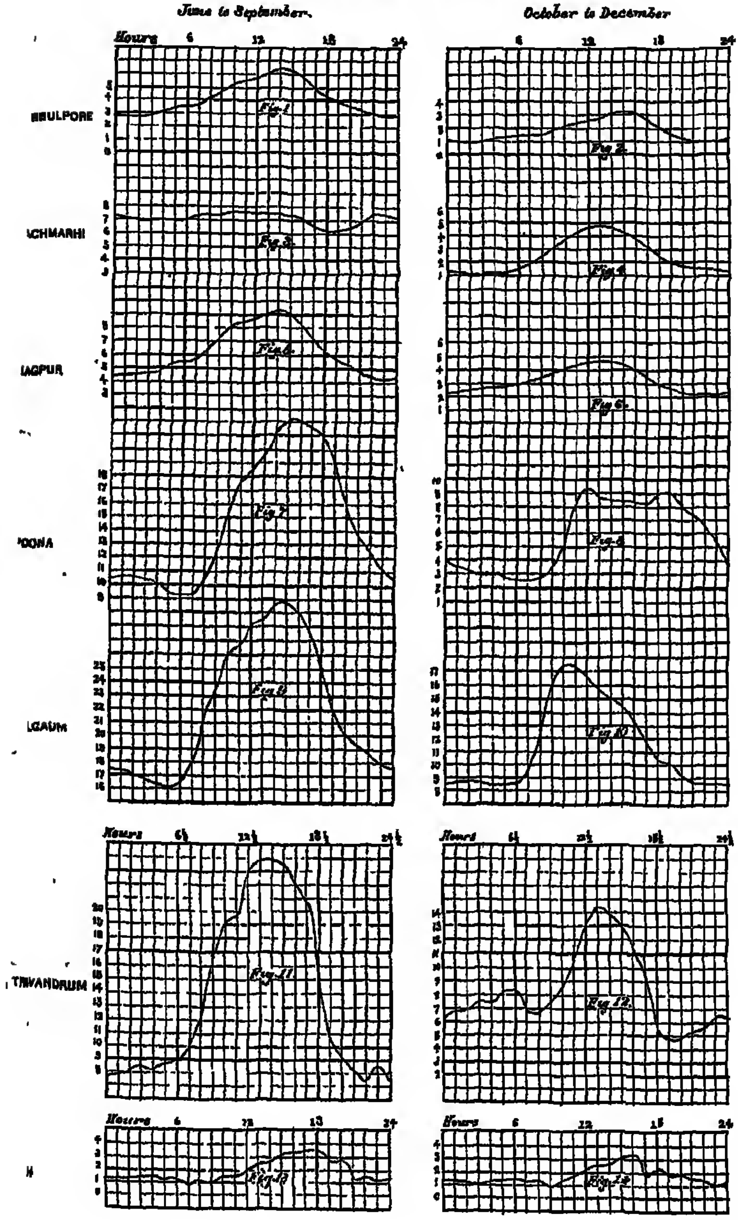
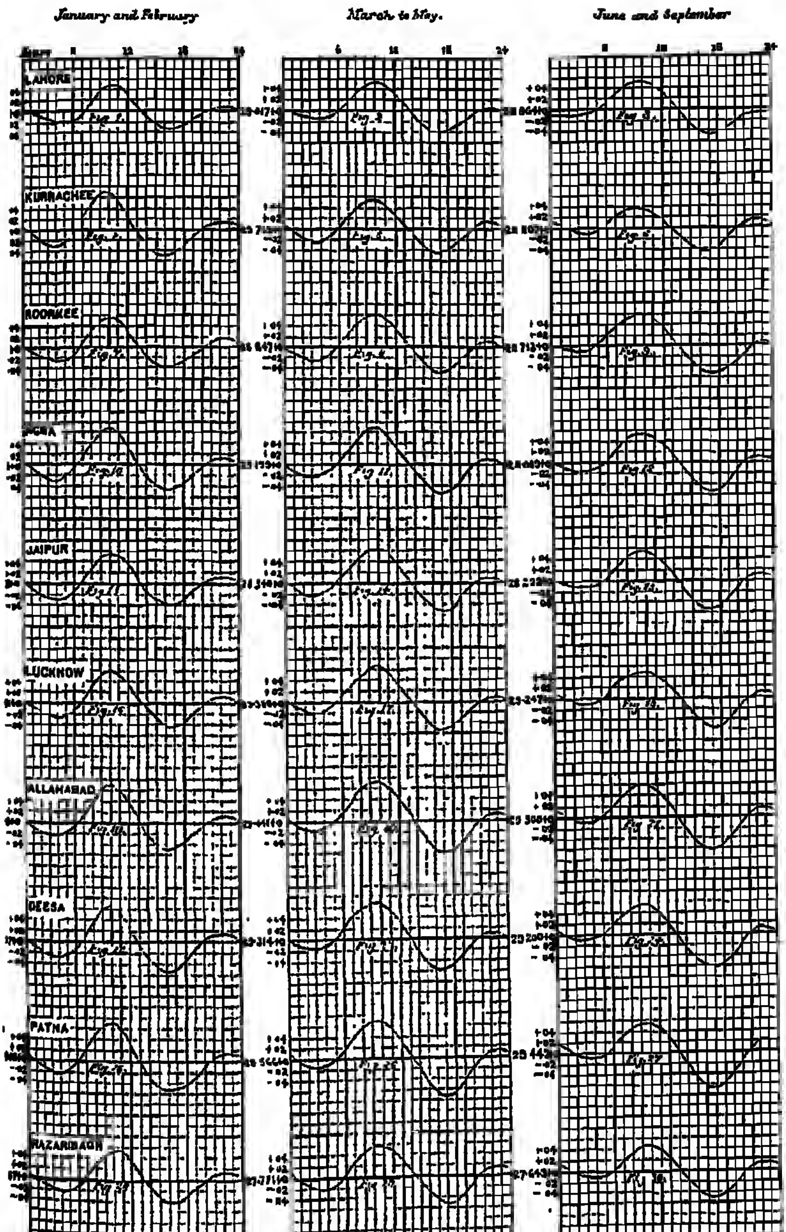


LIT BY J N HUMBLE

DIURNAL VARIATION OF PRESSURE IN



LITHO BY J. R. MURPHY

to a second solar action. The earth's surface is more or less heated by the solar radiation during the day hours and to a considerably greater extent than the neighbouring air masses, which are in turn heated directly by conduction and convection. The energy thus obtained by the surface directly from the sun is hence redistributed, a large portion of it being given up to the superjacent air which is heated, and in virtue of the actions thus set up, convective movements convey or carry the air with its increased energy upwards. These vertical convective movements hence distribute the energy thus obtained over the whole lower atmosphere to which they extend. As this transfer of energy from the earth to the atmosphere occurs at the earth's surface it may perhaps be termed "surface absorption" of energy by the atmosphere in contra-distinction to the "mass absorption" described in the preceding page.

In addition to the above, if we deal with a limited mass of air occupying a definite space, we have also to take into account the transfer of energy between that space and space external to it. This may be irregular or may be periodic. If irregular, it will not be necessary to take it into account in dealing with the periodical changes of energy in the atmosphere of which one manifestation is the diurnal oscillation of the barometer or variation of pressure.

For example the energy of the atmosphere may be modified by the addition of aqueous vapour as the result of evaporation or by the precipitation of rain as a result of the condensation of aqueous vapour. Cleveland Abbe (*vide* "Preparatory studies for deductive methods in storm and weather predictions", page 35) says, "the actual weight of vapour daily added to or condensed from the air can produce scarcely a change of ·01" in the barometer." Although larger changes are possible and probably occur in some parts of India due to this action, it is almost certain that this factor is in the present discussion, of small importance. The release of energy accompanying rainfall occurs so irregularly as to form no important or integral part of a periodic diurnal change.

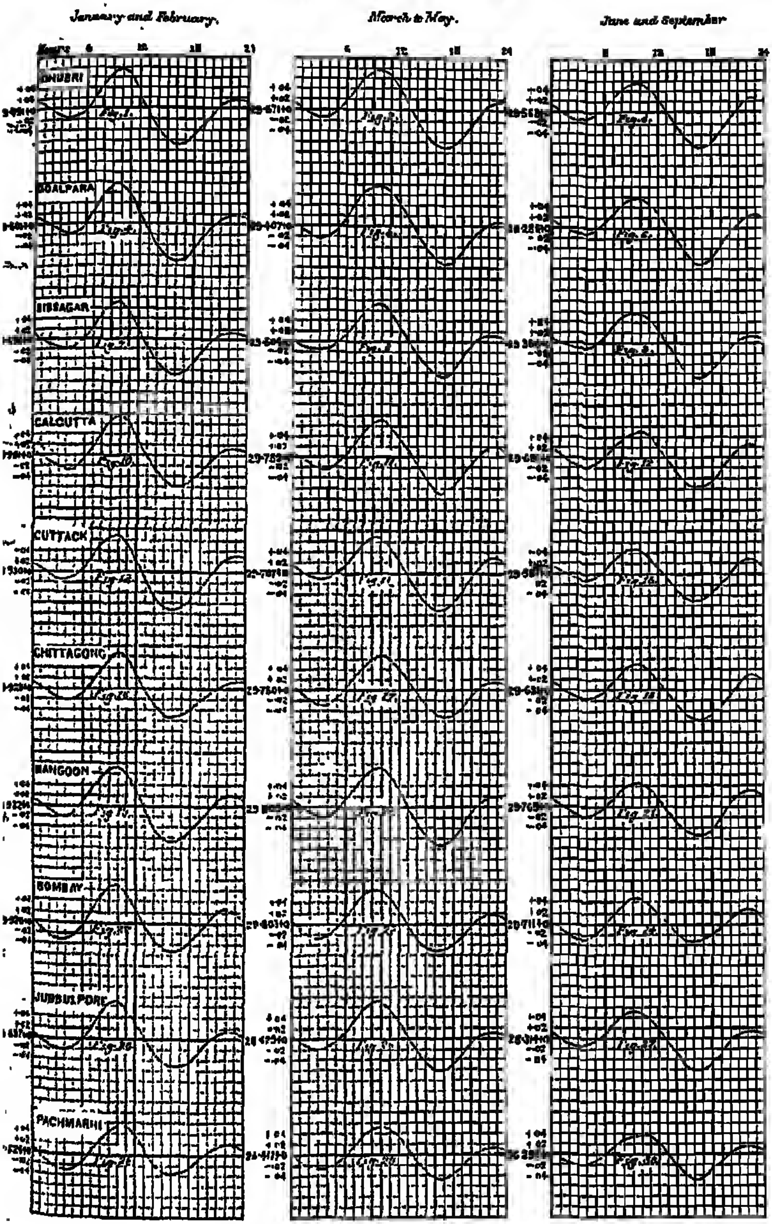
Hence we shall assume that the chief sources of variation of the atmospheric energy are those described above as (1st) *mass absorption and radiation*, and (2nd) *surface absorption and transfer*. We shall now examine these two causes of variation separately and compare the more important features of the diurnal variation of the atmospheric energy with corresponding features in the first two components of the Besselian resolution of the diurnal air pressure variation.

Absorption of Solar Radiation by the Atmosphere.—Absorption is the conversion of radiant energy or the energy of solar radiation into ordinary molecular energy. The absorption of solar radiation by the air, aqueous vapour, carbonic acid gas, etc., and by the action of dust has been a subject of elaborate investigation during the past 20 years.

The solar radiation or radiant energy passes through space probably undiminished in total amount, and hence diminishes in intensity per unit surface through which it passes as the inverse square of the distance until it reaches the earth's atmosphere. It is in part absorbed by the atmosphere and in part by the ground surface and the remainder is scattered or irregularly reflected at the ground surface or is absorbed by vegetation.

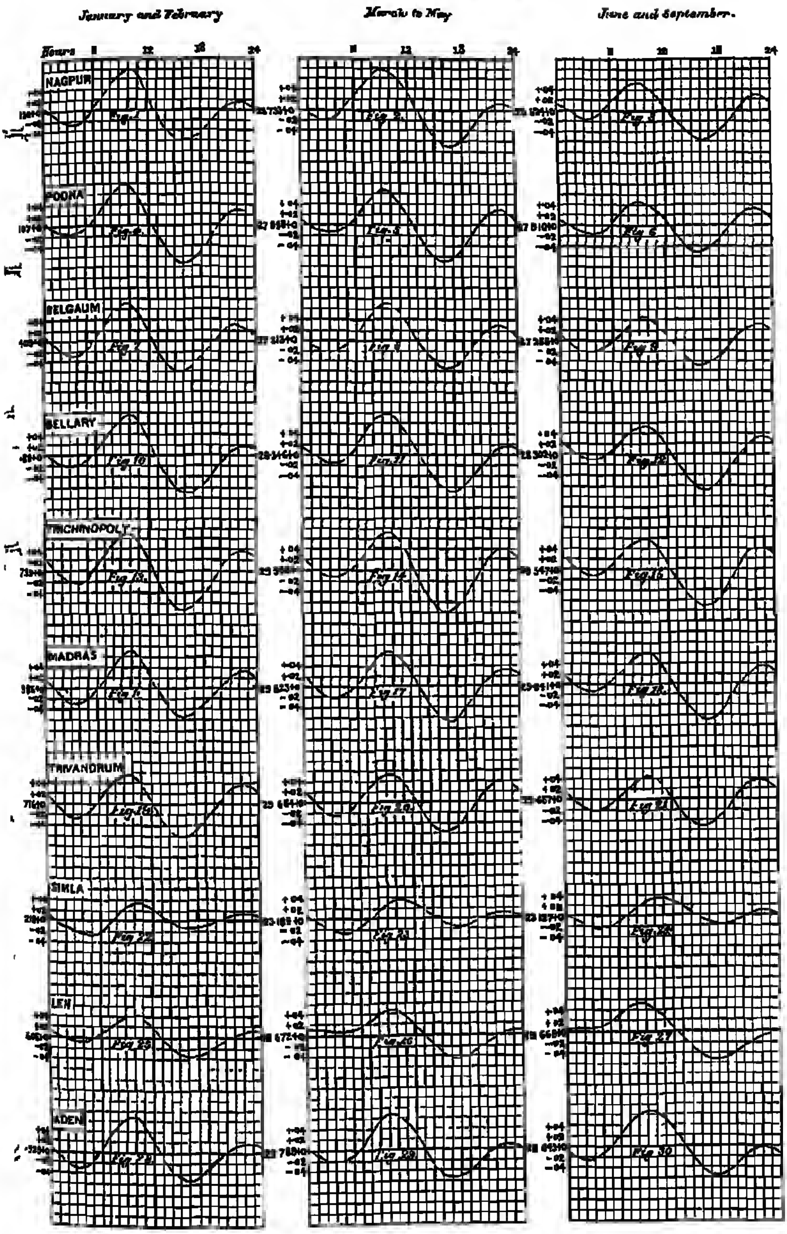
The action of dust in this respect was, so far as I am aware, first fully investigated by Tyndal. He proved, experimentally, that small dust particles act as obstacles to waves of small length and tend to break them up. When the size of the particles is large

DIURNAL VARIATION OF PRESSURE IN



LITHO BY J. D. ...

DIURNAL VARIATION OF PRESSURE IN



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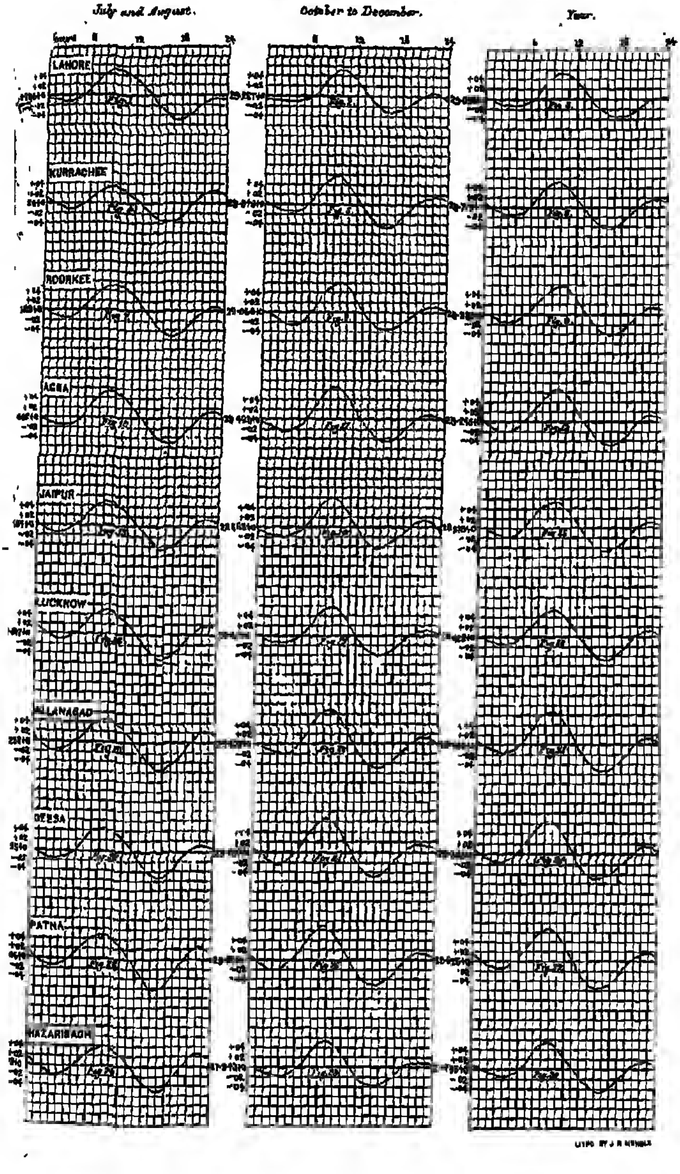
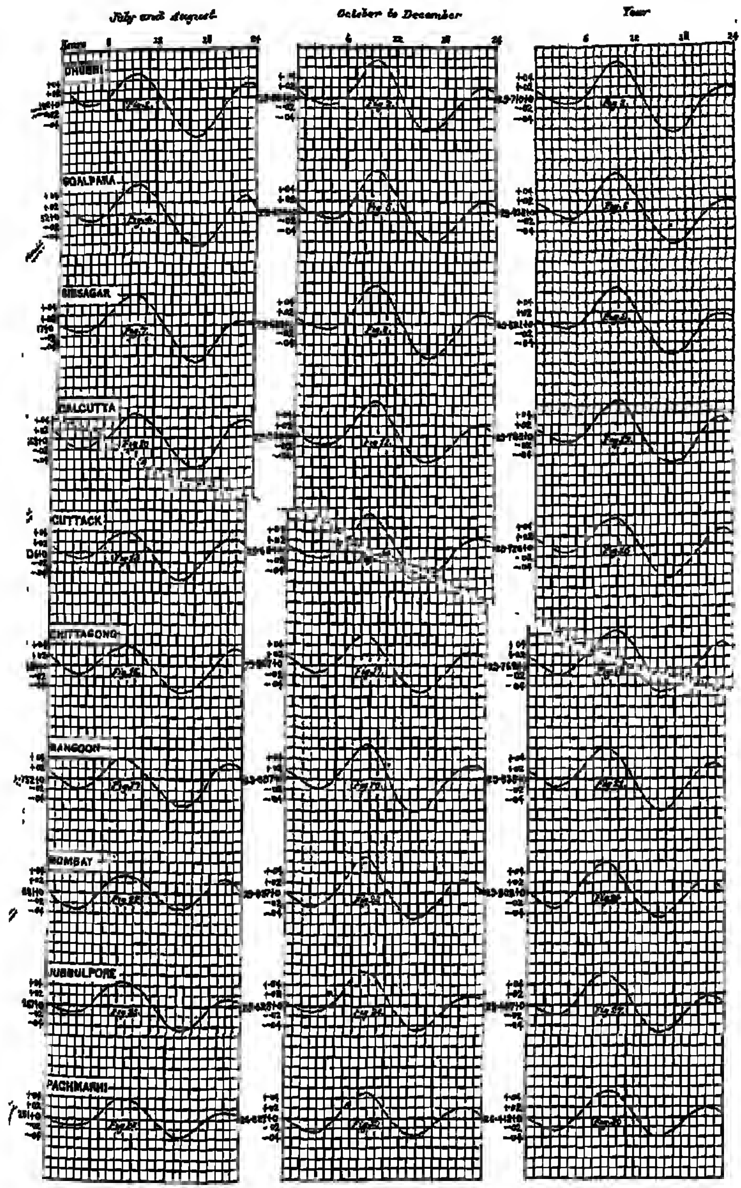


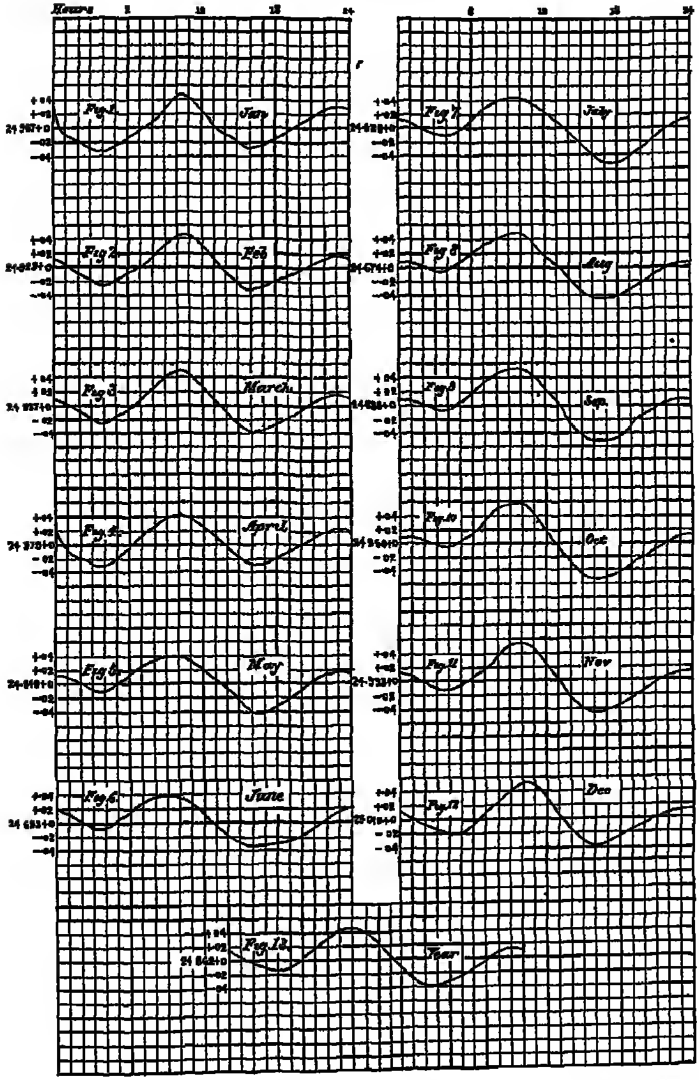
LITHO BY J. R. NEWMAN

DIURNAL VARIATION OF PRESSURE IN



LITHO BY J. F. MURELA

DIURNAL VARIATION OF PRESSURE AT SRINAGAR (Kashmir)



LITHO . J H MONBLK

dian Meteorological Memoirs:

BEING

OCCASIONAL DISCUSSIONS AND COMPILATIONS OF
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RELATING TO

INDIA AND THE NEIGHBOURING COUNTRIES.

Published by order of His Excellency the Viceroy and Governor General of India in Council,

UNDER THE DIRECTION OF

JOHN ELIOT, M A, F R S, C I E,
METEOROLOGICAL REPORTER TO THE GOVERNMENT OF INDIA AND DIRECTOR GENERAL OF INDIAN OBSERVATORIES

VOL. XII, PART III.

II.—DISCUSSION OF THE RESULTS OF THE HOURLY OBSERVATIONS RECORDED AT 29 STATIONS IN INDIA GIVEN IN VOLUMES V, IX AND X OF THE INDIAN METEOROLOGICAL MEMOIRS.

(FINAL CHAPTER AND PLATES)

CALCUTTA:
OFFICE OF THE SUPERINTENDENT OF GOVERNMENT PRINTING, INDIA.
1902.

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relatively to the light waves, the particles throw the waves back and scatter or break up the movement irregularly. When the particles are, on the other hand, small relatively to the amplitude of the light waves, the latter as it were pass round them with little loss of energy. Hence Tyndal came to the general conclusion that, as the magnitude of the dust particles in the upper and middle atmosphere diminishes with elevation, the shorter waves are more largely acted upon or broken up than the larger waves in the upper strata. In *other words, a species of selective absorption or scattering occurs, more largely in the* blue than the yellow and in the yellow than the red. It is partly in consequence of this action that shortly before and after sunset the sunlight passes through white, yellow, orange and red.

Lord Rayleigh and Abney have contributed important investigations dealing with this subject of which brief summaries are given in Hann's Meteorology.

The subject of the absorption of light and heat by gases, and more especially by aqueous vapour, was dealt with at great length by Tyndal, but his conclusions have not been accepted by later investigators. A brief account of these researches will be found in Ferrel's "Recent Advances in Meteorology," pages 56 to 59, or in Hann's Meteorology.

The most important investigations in this most interesting subject are those which have been carried out by Langley during the past 10 or 15 years and are given in No. 15 of the *Professional Papers* of the Signal Service entitled "*Researches on solar heat and its absorption by the earth's atmosphere*" and in "Annals of the Astrophysical Observatory of the Smithsonian Institution, Vol. I." *The following states the more important conclusions of these researches:—*

Langley's researches indicate that the solar constant (*i.e.*, the energy per square centimeter of surface per minute exposed normally to the sun before absorption by the atmosphere at the earth's mean distance) is three calories (a calorie being the amount of heat required to raise 1 gramme of water 1°C.).

He also estimates that in ordinary fine weather about 33 per cent., or one-third of this energy, is absorbed in its passage through the atmosphere.

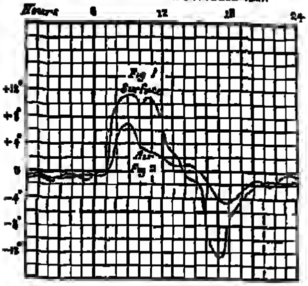
Langley also establishes that Breguet's hypothesis (that absorption is proportional to the density of the mass of the air in which it takes place) is not followed in the case of atmospheric absorption of the radiant energy as a whole and that the absorption is selective in character in two respects.

The most important result of his investigations and researches is the very great extension of the heat or ultra-red portion of the spectrum. Before his investigations observed spectrum extended down to about $\lambda = 1{\cdot}0\ \mu$ (or thousandths of a millimetre) He has mapped completely the solar spectrum down to $\lambda = 5{\cdot}3\ \mu$ (or thousandths of a millimetre) with its dark lines and bands and obtained what may be termed a very extended heat energy spectrum of the solar radiation.

He also states that the air or atmosphere is remarkably diathermanous to the dark heat or ultra-red rays of the sun. The supposition hitherto maintained that the ultra-red radiation was more absorbed by our atmosphere than the bright radiation is hence erroneous. The general result of his investigations is that each wave length is, broadly speaking, more transmissible, the further and further it is in the ultra-red radiation, and hence as an important result the "dark" heat escapes or passes through the atmosphere more easily than the "bright or luminous" heat.

Langley hence enunciates as a general principle that *the longer the wave length,*

DIURNAL VARIATION OF AIR AND SURFACE TEMPERATURE AT JAIPUR IN DECEMBER



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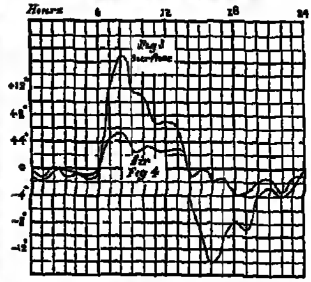
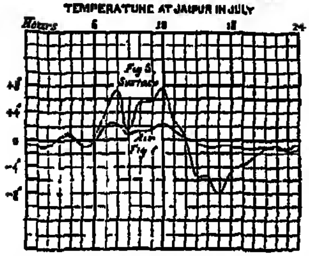
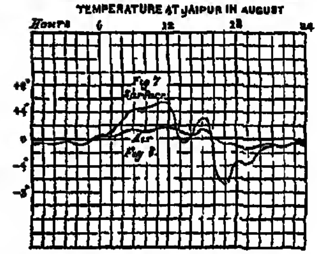


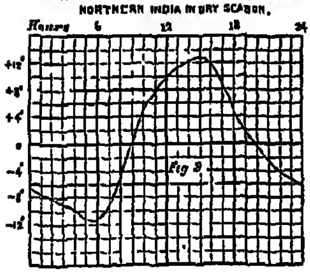
DIURNAL VARIATION OF AIR AND SURFACE TEMPERATURE AT JAIPUR IN JULY



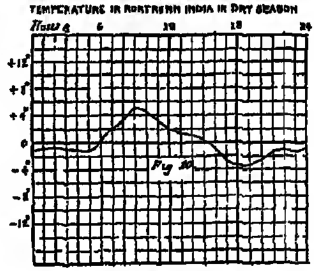
DIURNAL VARIATION OF AIR AND SURFACE TEMPERATURE AT JAIPUR IN AUGUST



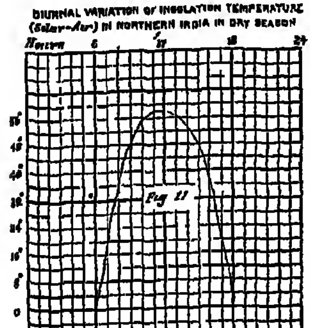
DIURNAL VARIATION OF AIR TEMPERATURE IN NORTHERN INDIA IN DRY SEASON.



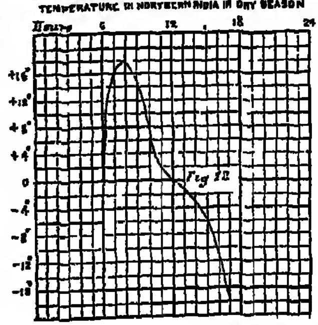
DIURNAL VARIATION OF RATE OF CHANGE OF AIR TEMPERATURE IN NORTHERN INDIA IN DRY SEASON



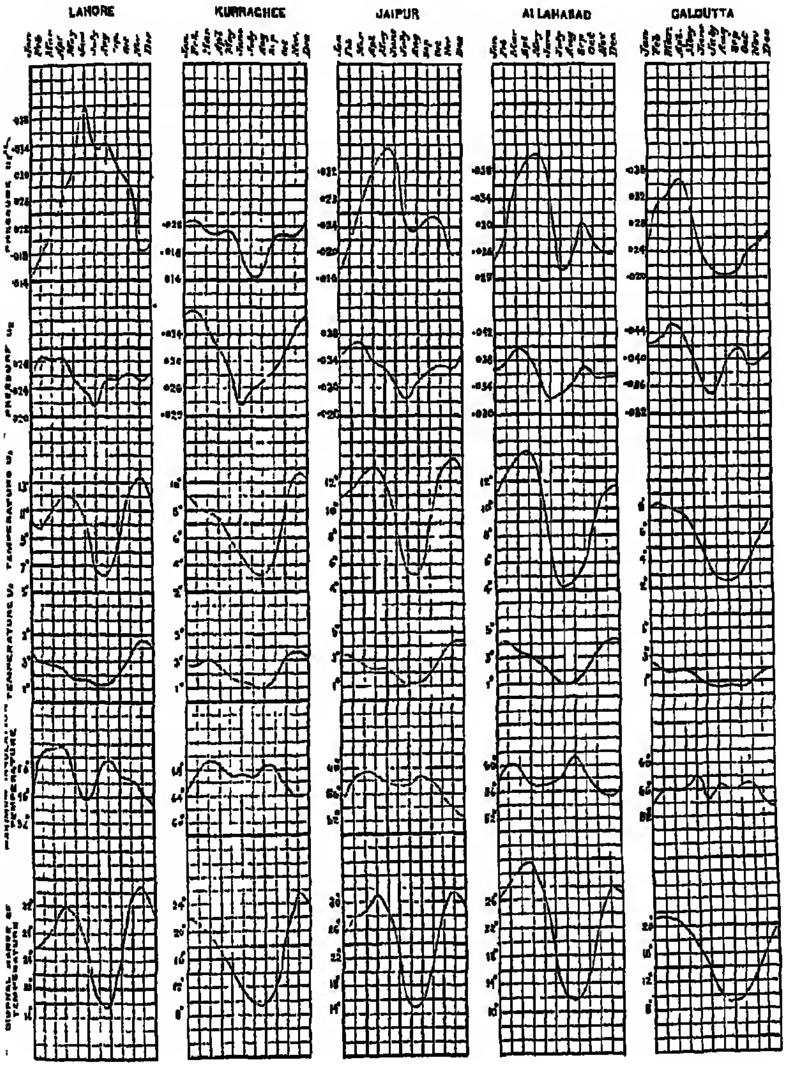
DIURNAL VARIATION OF INSOLATION TEMPERATURE (Solar-Air) IN NORTHERN INDIA IN DRY SEASON



DIURNAL VARIATION OF RATE OF CHANGE OF INSOLATION TEMPERATURE IN NORTHERN INDIA IN DRY SEASON



ANNUAL VARIATION OF THE AMPLITUDES OF U_1 AND U_2 OF AIR PRESSURE AND TEMPERATURE, MAXIMUM INSOLATION TEMPERATURE AND DIURNAL RANGE OF TEMPERATURE AT.—



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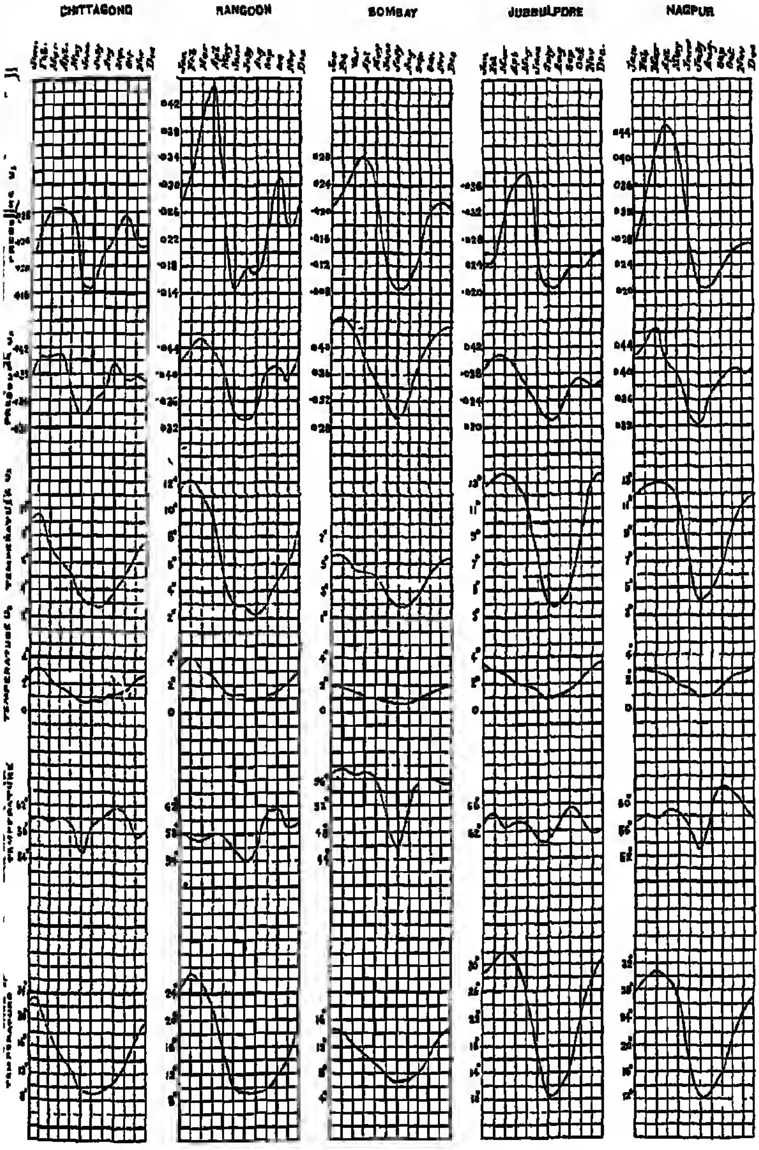
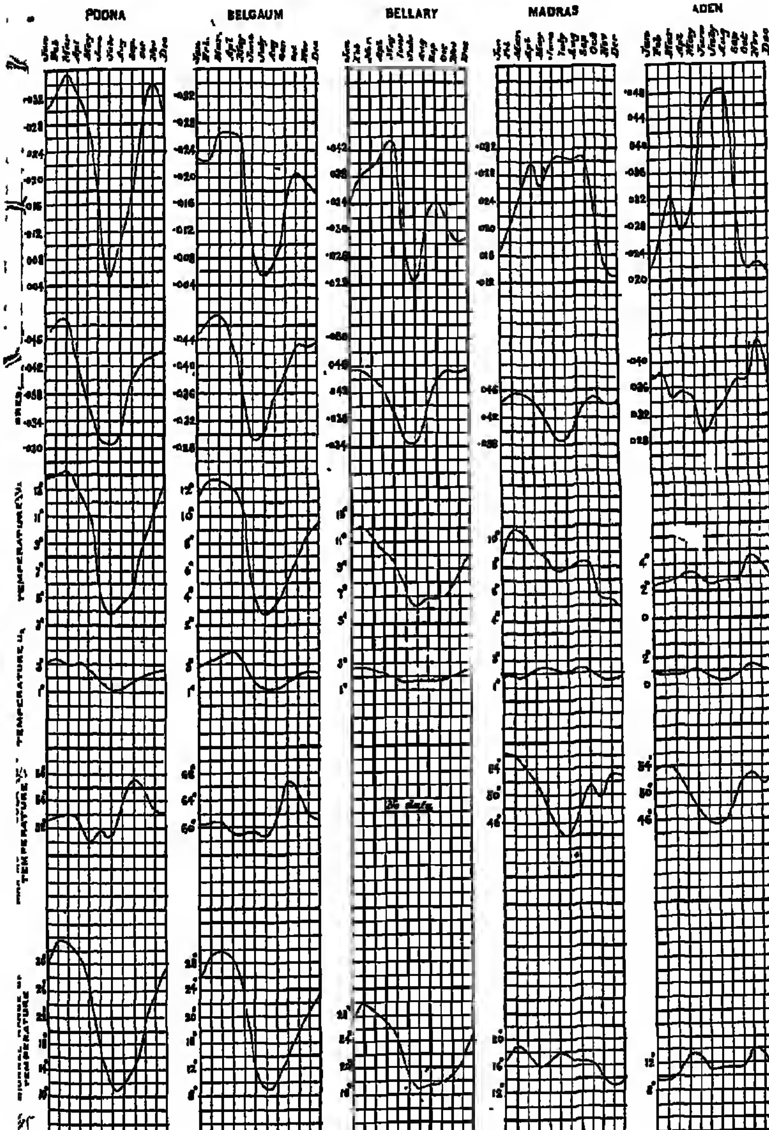
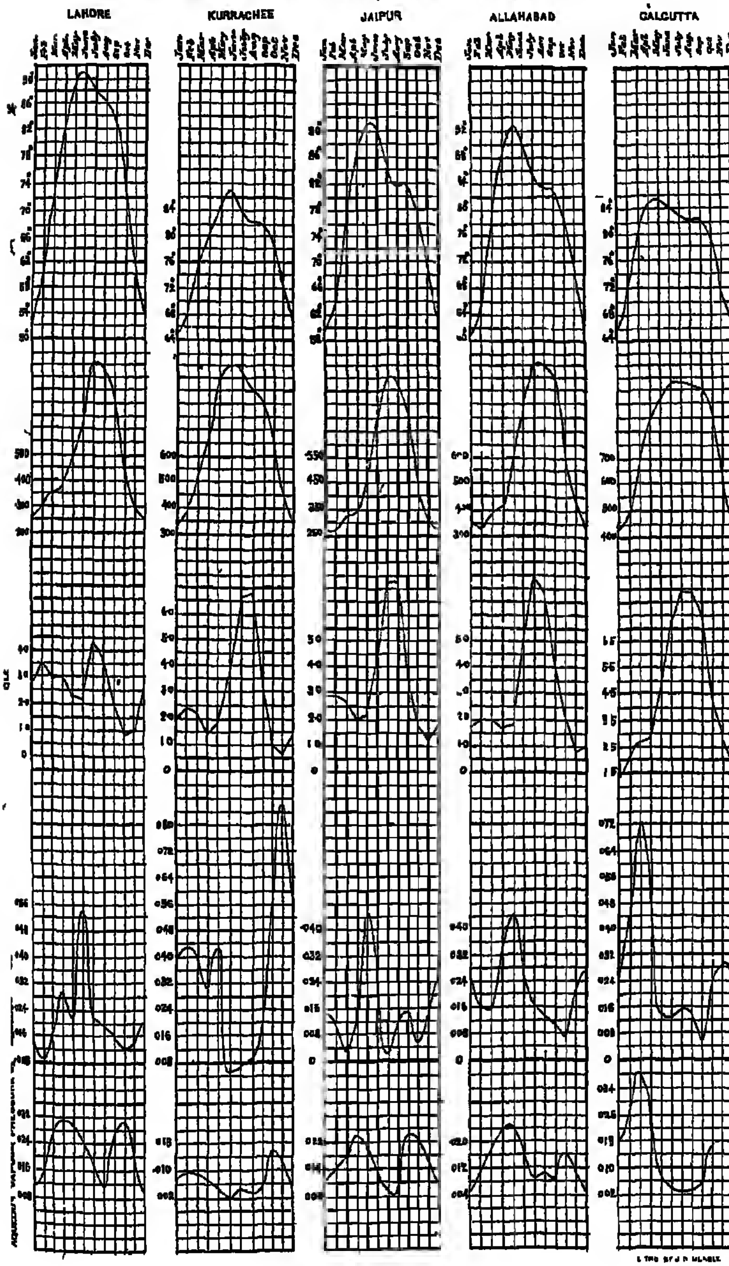


ANNUAL VARIATION OF THE AMPLITUDES OF U_1 AND U_2 OF AIR PRESSURE AND TEMPERATURE, MAXIMUM INSOLATION TEMPERATURE AND DIURNAL RANGE OF TEMPERATURE AT:–



LITHO BY J N MURRLE

ANNUAL VARIATION OF TEMPERATURE, AQUEOUS VAPOUR PRESSURE AND CLOUD AND THE AMPLITUDES OF U_1 AND U_2 OF AQUEOUS VAPOUR PRESSURE AT —



the greater is the transmissibility down to the obscured lowest limit of the solar spectrum, and that beyond this the transmissibility, so far as his experiments indicate, suddenly ceases.

Langley also states that his measurements indicate that the heat energy in the light regions of the solar spectrum is large in amount even when compared with that of the dark heat spectrum, and that it is very largely absorbed in its transmission through the atmosphere.

The observations on Mount Whitney prove the remarkable changing turbidity of the atmosphere, *i.e.*, the total absorption power varies largely from instant to instant.

The temperature of the earth's surface is in his opinion not determined primarily by the direct solar radiation The diurnal variation of its temperature is undoubtedly a direct solar effect, but the mean temperature of the earth's surface is determined by the temperature of the atmosphere which is much higher than it would be if it were perfectly diathermanous in consequence of its large absorption of the ultra-red portion of the solar radiation.

A most important statement made by Langley in the first of his memoirs quoted above is that the wave lengths of dark heat radiated from the earth are as yet unknown. No such wave lengths as those belonging to the heat radiated from the soil have in his opinion ever entered our atmosphere from the sun. Hence the results of his experiments and investigations do not necessarily invalidate the conclusions of Tyndal and others that the atmosphere is almost impermeable to dark heat of terrestrial sources of low temperature.

His latest investigations show that the heat from terrestrial sources, such as heated soil, is of much greater wave length than the major portion of that received from the sun.

The preceding remarks have given a few of the more important facts of the absorption of solar radiation by the atmosphere. Absorption includes all the various processes by which the energy of solar radiation is in part transferred to or transformed in the atmosphere in its passage through it. This transformation increases primarily the energy of that portion of the atmosphere and may hence affect either the potential or kinetic energy. The usual, if not the invariable, rule is that the potential energy of pressure is first modified, thus disturbing equilibrium of the then conditions. This is followed by motion or increase of movement or of kinetic energy with the accompanying slow re-adjustments of pressure.

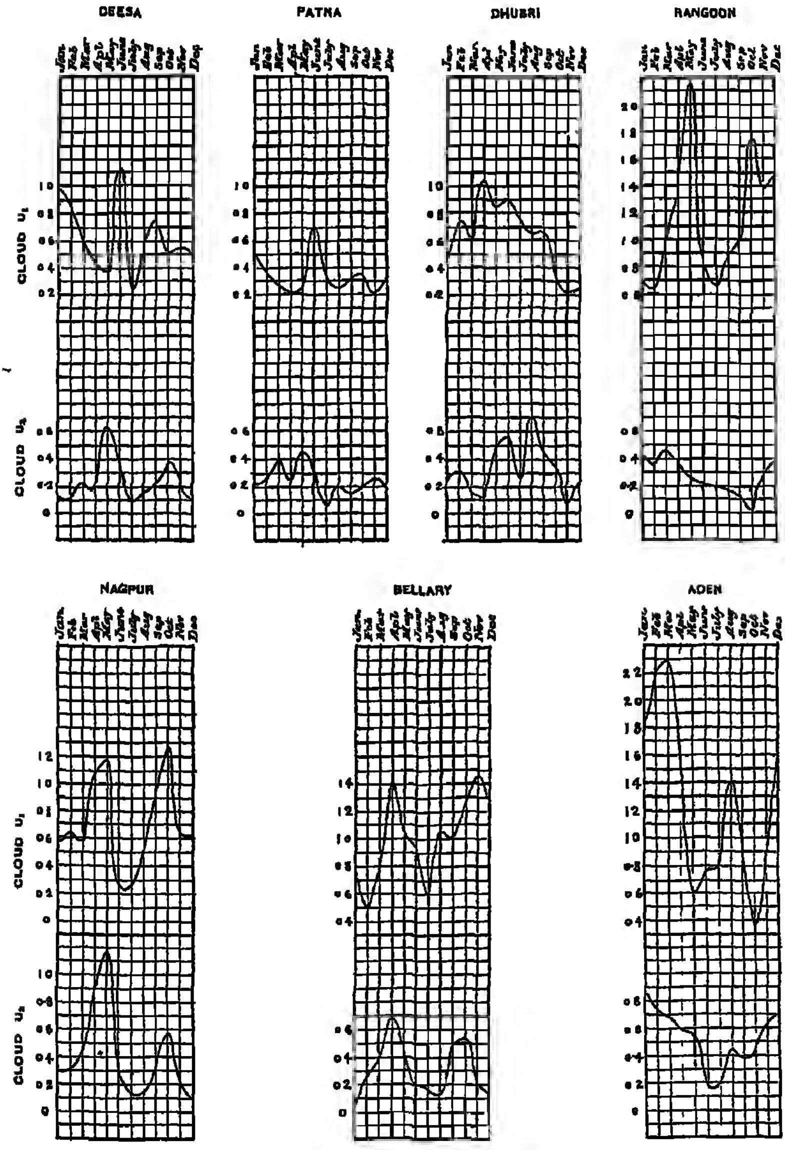
Little is as yet known of the actual variations of the quantitative amounts of absorption of the solar radiation under varying atmospheric conditions and of the emission by the atmosphere and ground surface.

The latest investigations have shown that the absorption of the ultra-red radiation is due chiefly to carbonic acid and aqueous vapour, and that the selective absorption of the higher or light radiation, greatest in the blue, violet and ultra-violet, is due to the disintegrative action of dust particles, chiefly in the upper atmospheric strata.

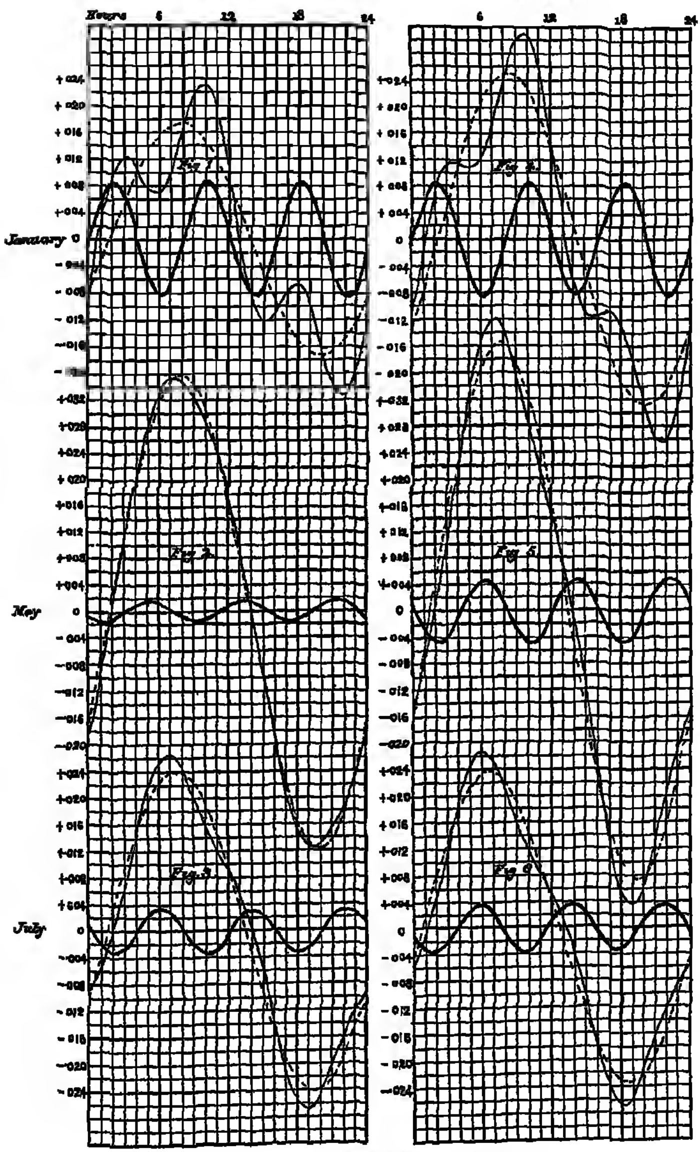
Abney has established that the amount of absorption in the light portion of the spectrum follows approximately Breguet's law, assuming a mean value for the constant of absorption for all wave lengths.

As the atmosphere or certain constituents of the atmosphere absorb large portions of the ultra-red radiation, it immediately follows from the general law that substances

ANNUAL VARIATION OF THE AMPLITUDES OF U_1 AND U_2 OF CLOUD PROPORTION AT –



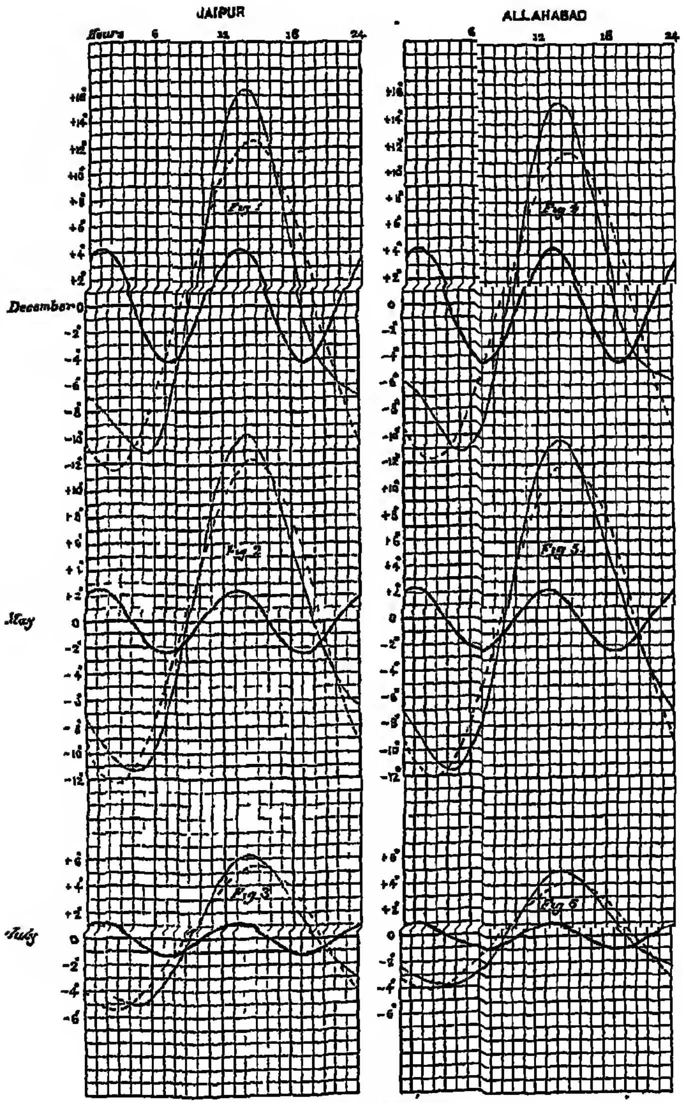
DIURNAL VARIATION OF U_1, U_2 AND U_1+U_2 OF PRESSURE FOR THE TYPICAL MONTHS OF THE THREE SEASONS OF THE YEAR AT_



---------Broken lines represent U_1
————Thick do do U_2
————Thin do do U_1+U_2

LITHO BY J R MONDAL

DIURNAL VARIATION OF U_1, U_2 AND U_1+U_2 OF TEMPERATURE FOR THE TYPICAL MONTHS OF THE THREE SEASONS OF THE YEAR AT –



- - - - - - - Broken lines represent U_1.
——— Thick do do U_2
——— Thin do do U_1+U_2

LITHO BY J H HIGGINS

which absorb any particular kind of radiation will in general be a source of radiation when heated of the same kind (Stoke's law), that the atmosphere will emit the same radiation. The amount of absorption increases with the depth or thickness of the atmosphere and hence it is greater with a low than with a high sun. It varies, on the other hand, with the length of the day, being least in the cold weather and greatest in the hot weather. It also varies largely with the amount of dust in the air and the amount of aqueous vapour present in the air and hence with its humidity.

Another important factor in varying the amount of absorption is the presence or absence of cloud. When the solar radiation falls upon a cloud the small vesicles or particles probably break up the waves if small enough. The most important action in this case is the evaporation of a portion of the cloud (the upper surface) and the conversion of the solar energy into the energy of molecular change. This may reappear or be given up to the atmosphere at a subsequent stage of condensation, but it is at this stage absorbed in a process which in no way affects the pressure of the surrounding atmosphere.

A large number of investigations on the subject of absorption and radiation by the atmosphere and of the ground surface have been recently made on the Continent. Summaries of the more interesting results of these investigations are given in Hann's Meteorology which indicate that the ground surface and atmosphere both radiate heat energy largely. They are not apparently sufficiently exact to enable us to follow the variations of the energy of the atmosphere, annual or diurnal, due to absorption and radiation except in a very general way.

This absorption of solar radiation by the atmosphere is *nil* over any given area during the night hours, is probably a maximum sometime after sunrise, decreases to a minimum about noon and thence increases to a secondary maximum before sunset and finally decreases (*vide* Explanation, page 385) to *nil* shortly after sunset.

Of the radiation from the earth's surface through the air and the amount which is absorbed in its passage through the air, little is known. Some data are given in Hann's Meteorology. It is almost certainly small to moderate in amount compared with the solar radiation and is greater by day than by night.

The radiation from the whole mass of the atmosphere itself is almost certainly moderate to considerable in amount. The following gives Cleveland Abbe's estimate (*Vide* Preparatory Studies for Deductive Methods in Storm and Weather Predictions, page 81).

"As the annual radiation from the sun does not cause a sensible increase in the earth's temperature from year to year, one must conclude that the loss by terrestrial radiation is fully equal to the amount of heat received. Now, a surface normal to the solar rays receives 3·0 calories per minute per square centimeter, and the quantity of heat received between latitudes 30° N and 30° S vastly exceeds that received on the two polar sides of these parallels, consequently the heated equatorial air must flow north and south into regions where it can cool sufficiently to balance this excessive reception of heat at the equator. The general co-efficient of emission of the atmosphere into space, which co-efficient is effective almost uniformly over the whole surface of the earth, must be sufficient to dispose of all the heat that the earth receives from the sun or on the average about 0·404 calories per square centimeter per minute (adopting Langley's value of 3·0 for the solar constant)."

Considering only a limited portion of the earth's surface, as for example, India, Cleveland Abbe's remarks quoted apply fully with the exception that, due to the general atmospheric oscillation, there is a steady transfer of heat or energy from the tropical to the polar regions There is, however, in neither region a permanent storage or continued accumulation of energy

The preceding remarks have hence suggested that there is a marked variation of energy during the diurnal period over the Indian area. There is an increase during the day hours due chiefly to the absorption of solar radiation which is probably greatest about sunrise, and sunset and a decrease during the night hours due to atmospheric radiation the rate of which is probably greatest in the early morning.

The effect of the addition of energy to the atmosphere during the day and the variation of energy due to atmosphere mass absorption and radiation is to give rise to change of air movement and of pressure. The actual pressure changes are small in amount, as the amount of transfer due to the movements set up is very small relatively to the mass of the atmosphere over the area in question, or to express the facts in another form—the effect on the air movement is cumulative but is not so in the case of pressure, as any slight change of pressure gives rise to movement which tends to restore previous pressure conditions Hence the actual pressure changes are residual and not cumulative changes

It is evident that the pressure variation will be roughly proportional to the amount and character of the absorbed solar energy and that (more especially) variation of one will be proportional to the other if they are related as cause and effect

We have now to compare the chief features in the seasonal and local distribution of this absorption with certain features in the variation of the second component corresponding to and probably correlated to these features.

Seasonal variation of mass absorption in the dry season.—During the dry season in India, the total amount of absorption of solar radiation per diem in ordinary weather almost certainly varies little from day to day There is slight variation from day to day due to varying amounts and distribution with elevation of dust particles consequent on varying air movements, variations in extent and depth of cloud, chiefly cirrus, and perhaps variations in the amount and distribution of aqueous vapour present in the atmosphere consequent on the variations of air movement and the general air circulation The variations of each element are almost certainly small in amount during the normal fine weather of the period The distribution of aqueous vapour and dust with elevation, whilst probably modifying to some slight extent the distribution of amount of absorption with elevation, probably affects very slightly the total amount of absorption from the highest to the lowest stratum of the atmosphere.

The chief variations during the period affecting absorption are—the thickness or depth of the atmosphere through which the solar radiation passes (depending upon the elevation of the sun) and the diurnal period of the action of absorption (or the length of the day proper) There will hence be a slight general seasonal variation due to these causes more marked in Northern than in Southern India. The variation in the amount of absorption of the energy of solar radiation will depend in the dry season chiefly upon these two factors These two factors are opposed to each other their effects varying inversely with the seasonal march or midday elevation of the sun. Decreasing elevation of the sun is accompanied with increasing absorption during the day period which, however decreases in length, and hence gives a shorter daily period of absorption and *vice versâ*

In consequence of this opposition, the variation during the dry weather period of similar meteorological conditions is almost certainly small in amount. The amount of absorption will be increased by the presence of dust, etc, in the air. The amount of dust present in the air in India is in some months, especially March, April and May, very large. Combining these results, it is most probable that in India the absorption in the dry weather will vary very slightly in Southern India and will vary to a slight or moderate extent in Northern India

Seasonal variation of mass absorption in the wet season—During the wet season, conditions are quite different. The lower air movement (from the sea to the land) is of great depth, and hence the lower and middle strata up to 10,000 or 15,000 feet are almost saturated by the continued advance of the humid monsoon currents across the coasts of India into the interior. There is hence a great depth of cloud during this period over by far the greater part of the country, the extent or thickness of which depends upon various local conditions, more especially distance from the sea and position with respect to hills and also with respect to the goal of the lower air movement in Upper India. The aqueous vapour is not in the invisible gaseous stage but is visible as cloud and in the form of small particles or vesicles of water condensed according to Aitken about dust particles and forming cloud masses and in part at least according to the latest researches to ionisation of the air and other conditions

A considerable to a large part of the solar radiation is absorbed by the cloud and is transformed into the latent heat of evaporation and consequently in no way affects the pressure or movement of the atmosphere. This portion of the solar radiation given up or absorbed during the process of evaporation, while undoubtedly increasing the total energy of the atmosphere, does not increase that part of the energy which directly affects the pressure of the atmosphere and gives rise to those movements which contribute to the pressure changes. If condensation of any part of this evaporated vapour and cloud formation should follow in the same mass of air, an equivalent amount of heat of condensation or energy of molecular change will be set free. As, however, it will usually be, judging from the occurrence of rainfall, given out irregularly and locally it will not contribute to the periodic actions giving rise to the regular and diurnal oscillatory change of pressure and may be left out of consideration Hence, due to this action, the total amount of absorption per diem will be much less in the wet than the dry season and will be least when the south-west monsoon rainfall is greatest and most general, *i.e.*, in July and August. There will also be local variations or differences between the amounts in the coast districts and the dry districts of the interior and between Southern India and Northern India.

The preceding remarks hence indicate that there will be a well marked maximum of absorption in the dry season and a minimum in the height of the rains. The explanation of the action of the clouds in diminishing what may be termed from this point of view effective absorption, also suggests that the rapid clearing of the skies at the end of the rains which occurs at most stations in the interior, more especially in Northern India, will give rise to a sudden increase of absorption, or a feeble secondary maximum, followed almost immediately by a very feebly marked minimum interrupting as it were the regular course of progress of this period due to the combined results of decreasing elevation of the sun and decreasing length of day.

Hence the sudden change in India from the dry season to the wet season and *vice versa* should be accompanied by a sudden and considerable diminution in the first case and increase in the second case of the total diurnal absorption of the solar radiation utilized in heating the atmosphere The seasonal minimum due to the change from the dry to the wet season conditions should hence occur in the height of the rains when cloud is most abundant and densest and will be practically simultaneous over the whole of India, and will be much more pronounced than the maximum in January due to the variation of the mass absorption of the solar radiation with season

The combination of the actions explained above in the two seasons of the year will hence give two maxima and minima values of the diurnal absorption of solar energy in its annual variation, and hence probably in the amplitude of the diurnal oscillation, so far as it depends upon this action The epochs of maxima and minima values will probably differ to some extent in Northern and Southern India due to differences in the midday elevation of the sun, length of the day, of meteorological conditions and other factors

The following is a summary of the preceding discussion —

(1) The absorption of the energy of solar radiation takes place through the whole depth of the atmosphere. Its amount depends primarily upon the depth of the atmosphere through which the action occurs.

(2) The total diurnal absorption during the dry season in India depends chiefly upon two factors which operate inversely to each other, and the variations of which are small, *viz*, the elevation of the sun and the length of the day Hence the variation of the total diurnal absorption is small in amount during the normal dry weather of the period

(3) The maximum absorption in India is probably one or two months after the sun has its lowest elevation and in February or March, in February at the coast stations and in March at stations in the interior, where the amount of dust in the hot weather is large It hence varies slightly in time depending to some extent upon local conditions

(4) The total diurnal absorption decreases slightly from this maximum in February or March up to the end of the dry hot weather in April or May according to the period when the dry and almost cloudless weather of the dry season terminates. This is at the end of April in the West Coast, Lower Burma and the greater part of North East India in May in the interior of Northern and Central India and in June in Upper India

(5) There are considerable differences between the amount of the total diurnal absorption in the Peninsula and Northern India, more especially North-Western India

(6) There is a considerable and rapid decrease of the amount of absorption from the commencement to the height of the rains in June or July and a similar and a smaller increase at the end of the rains in September and October at stations in the interior of Northern India and the North Deccan

(7) There is hence a very slight tendency to a secondary maximum at the end of the rains in the areas where it occurs rapidly and abruptly.

(8) The energy of the atmosphere through the processes of absorption (of the solar and terrestrial radiation) and of radiation has hence generally in India a double oscillation or variation daily, having two maximum values about sunrise and sunset and two minimum values probably about noon and in the early morning. The most important features of the variation are due to the variation in the absorption of the solar radiation during the day.

(9) It is not possible to give approximately exact measures of the total diurnal mass absorption of the solar energy by the atmosphere or of its annual variation.

Comparison of annual variation of the amplitude of the second component and of variation of energy due to mass absorption by the atmosphere.—We shall in the first place show that the annual variation of the amplitude of the second component has maximum and minimum phases similar in character and occurring at the same period as those of the mass absorption of radiation by the atmosphere.

For convenience of reference we repeat a table given in page 291 and which shows at a glance the chief features of the amplitude of the second component in the four large divisions of stations in the plains of India, and at stations in mountain valleys and on mountain crests :—

Area.	Mean monthly values of the amplitude of the second component in											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	"	"	"	"	"	"	"	"	"	"	"	"
Extra-Tropical India Inland .	·03722	·03851	·03869	·03720	·03400	·03113	·02918	·03253	·03535	·03538	·03606	·03633
" " Coast .	·03854	·04040	·04025	·03875	·03449	·03032	·03145	·03389	·03642	·03565	·03749	·03804
Tropical India Inland . .	·04532	·04749	·04767	·04498	·04058	·03397	·03349	·03761	·04189	·04431	·04371	·04371
" Coast . .	·04414	·04568	·04548	·04317	·03894	·03532	·03341	·03669	·04022	·04205	·04459	·04314
Mountain Crest stations . .	·02531	·01608	·02837	·03043	·02669	·02224	·02372	·02573	·02697	·02828	·02602	·02891
" Valley " . .	·02866	·02789	·02937	·02705	·02410	·02170	·02187	·02354	·02769	·02769	·02821	·02764

The following are the more important inferences from the data of the preceding table :—

(1) The amplitude of the second component is greatest in February or March and least in June or July.

(2) The variation of the amplitude is small during the dry season from October to April, both actually and relatively to its absolute value. It ranges on the mean of all stations in Extra-Tropical India Inland between ·03538" in October and ·03869" in March (a difference of only three thousandths of an

inch or nine per cent. of the mean value), and in Tropical India Inland between ·04371" in November and December ,and ·04767" in March or barely four thousandths of an inch.

(3) The amplitude decreases considerably at the commencement of the rains, and attains its minimum value generally in July when the cloud and rainfall is on the whole greatest. The absolute variation of the amplitude averages ·008" in Extra-Tropical India and ·013" in Tropical India.

(4) The mean value of the amplitude of the second component during the four months period, June to September, ranges in Tropical India Inland between ·03349" and ·04189" (a variation of 23 per cent. on the mean value of the period), and in Extra-Tropical India Inland between ·02928" and ·03535" (or 21 per cent. of the mean value for the period). The variation of amplitude is hence considerably greater during the short period of the rains proper than in the whole dry season from October to April and is also slightly greater in the Peninsula than in Northern India.

(5) The epoch of the maximum amplitude is about a month earlier at the coast than the interior stations. This acceleration at the coast stations is more marked in the dry season than in the rains. The simplest and most probable explanation is that it is in part due to the larger amount and earlier increase of cloud in the coast districts than the interior which is as marked in the hot weather as at the commencement of the rains, and in part to the rapid increase of dust in the interior.

(6) The amplitudes at stations in mountain valleys and on mountain ranges are subject to the same law of variation as the plain stations and are practically proportional to the actual pressure. Data establishing this have been already given (*vide* pages 292-93). This is in strict accordance with the supposition that the effect is due to action through the entire depth of the atmosphere, and hence increases in amount with increasing depth or decreases with elevation above the general level and according to the mass of air above the point or which is the same thing, the barometric pressure The rate of decrease with elevation will, however, differ considerably in the rainy season and the dry season.

(7) The amplitude of the second component is throughout the whole year greater in Tropical than in Extra-Tropical India but is subject to the same annual variation.

A comparison of these facts with the corresponding facts of the variation of the absorption of solar radiation by the atmosphere at once shows that the annual variation of the amplitude of the second component runs parallel with the diurnal variation of the direct atmospheric absorption of the solar radiation in all its features (1), (2), (3), (4), (5) and (6) given in page 338.

The correspondence between the two series of variations is further confirmed by the following examination of the whole of the data for the thirty stations at which hourly observations have been recorded in India.

A. The primary maximum.—The following gives data showing the epoch of the absolute maximum amplitude of this component in India :—

Month	Number of stations in which the amplitude is an absolute maximum in the given month			
	Extra-Tropical India		Tropical India	
	Inland	Coast	Inland.	Coast.
January	2	0	0	0
February	3	1	2	2
March	9	0	5	3
April	1	0	0	1
Total .	15	1	7	6

There is hence a moderate range of variation in the occurrence of the epoch of maximum amplitude of at least two months. On the mean of all stations it is in March over the whole of India.

The following gives the names of the stations grouped according to the months.—

Month	Extra-Tropical India	Tropical India.
January	Lucknow	
	Srinagar . . .	
February	Deesa	Trivandrum.
	Kurrachee	Trichinopoly.
	Agra	Bellary.
	Lahore	Bombay.
March	Calcutta	Madras
	Goalpara	Rangoon
	Dhubri	Belgaum.
	Hazaribagh	Poona
	Patna	Nagpur.
	Allahabad	Cuttack.
	Jaipur	Pachmarhi
	Simla	Jubbulpore.
	Leh	
April	Roorkee	Chittagong

The following table gives the values of the maximum amplitudes in February or March at these stations:—

Month	Extra-Tropical India. Station.	Absolute maximum amplitude.	Tropical India. Station.	Absolute maximum amplitude.
		″		″
February	Deesa	·04092	Trivandrum	·04775
	Kurrachee	·03730	Trichinopoly	·05223
	Agra	·03900	Bellary	·04575
	Lahore	·02882	Bombay	·04400
March	Calcutta	·04510	Madras	·04571
	Hazaribagh	·03777	Belgaum	·04756
	Allahabad	·03995	Rangoon	·04531
	Patna	·04165	Poona	·04870
	Dhubri	·04615	Cuttack	·04695
	Goalpara	·04639	Nagpur	·04631
	Jaipur	·03683	Pachmarhi	·03615
	Simla	·02400	Jubbulpore	·04063
	Leh	·02172		

The preceding data suggest the following:—

(1) The differences between the amplitudes in February and March are small, averaging less than two thousandths of an inch for each of the four large groups of plains stations (*vide* table, page 339) They are so small as to be within the limits of error of observations in India if account be taken of the limited number of observations from which those values are derived. This is further confirmed by the irregularity of the order of the stations according to months

(2) The month of maximum amplitude at the inland stations is in the great majority of cases March

(3) There is a very slight tendency to the earlier occurrence of the maximum amplitude at the coast than the inland stations. The number of stations is not sufficient to justify the assumption of this as a certain inference.

B. The primary minimum. The following gives comparative data for the absolute or primary minimum:—

Month.	Number of stations at which the amplitude is an absolute minimum in the given month. Extra-Tropical India. Inland.	Coast.	Tropical India. Inland.	Coast.
June	8	1	4	1
July	7	0	6	4
Total	15	1	10	5

There is hence a moderate range of variation in this epoch as in that of the absolute maximum. There is a slight tendency for the minimum to occur earlier in Extra-Tropical India than in Tropical India. On the mean of all stations the absolute minimum amplitude of the second component occurs about the end of June or beginning of July :—

Month.	Extra-Tropical India.	Tropical India.
June	Leh	Chittagong.
	Srinagar	Belgaum
	Simla	Aden.
	Roorkee	Trichinopoly.
	Lucknow	Agatua.
	Dhubri	
	Allahabad	
	Kurrachee	
	Hazaribagh	
July	Lahore	Jubbulpore.
	Agra	Pachmarhi.
	Sibsagar	Nagpur.
	Jaipur	Cuttack.
	Patna	Bombay.
	Deesa	Poona.
	Calcutta	Rangoon.
		Bellary
		Madras.
		Trivandrum

The distribution of stations according to the period or month of occurrence of the minimum amplitude of the second component exhibits an irregularity similar in character to that shown by the maximum amplitude. There is a slight tendency towards its earlier occurrence in Extra-Tropical than in Tropical India. This is probably due to the fact that over a considerable portion of the Peninsula the change from the dry season to the hot season is much less marked than in Northern India. In Extra-Tropical India the monsoon conditions of cloud are usually as pronounced in June as in July in the hill and submontane districts of Northern India. But as in the previous case, it is probable that a part of the irregularity is due to errors of observation and to the number of observations being insufficient to give the amplitudes of the Besselian components correct to the fourth decimal place. The slight difference in the actual values for the months of June, July and August at the stations in the preceding list or table will be seen by reference to the Table CXV, page 307.

C. The secondary maximum.—At eight stations (four in Extra-Tropical and four in Tropical India) the monthly values of the amplitude of the second component have only one maximum and minimum in the course of the year. These stations are Sibsagar, Goalpara, Kurrachee, Agra (doubtful), Cuttack, Poona, Trivandrum and Bombay, all on

D 2

or in the immediate neighbourhood of the sea coast or in the damp cloudy Assam valley, where the transition from the conditions of the rainy to the dry season is slowest and most prolonged. On the supposition that the second component is the direct effect of the mass absorption of solar radiation by the atmosphere, the absence of the secondary oscillation or variation is evidently a result of the cloud action explained above.

The following table gives the number of stations, arranged according to months, at which there is a secondary maximum in the annual variation of the amplitude of the second component :—

Month.	Number of stations at which the amplitude is a secondary maximum in the given month.			
	Extra-Tropical India.		Tropical India.	
	Inland.	Coast.	Inland	Coast.
September	7	0	0	0
October	2	0	4	0
November	0	0	2	0
December	0	2	1	0
Total .	9	0	7	2

The preceding data indicate that there is a marked tendency for the epoch of the secondary maximum to occur earlier (on the average of all stations, approximately a month) in Extra-Tropical than in Tropical India. The mean epoch is September in the former area and October in the latter.

The following arrangement of the stations shows clearly the southward march of the epoch of the secondary maximum values :—

Month.	Extra-Tropical India.	Tropical India.
September	Leh	
	Lucknow	
	Dhubri	
	Patna	
	Allahabad	
	Hazaribagh . . .	
	Calcutta	
October	Lahore	Jubbulpore.
	Jaipur	Nagpur
		Rangoon.
		Belgaum
		Madras.
		Trichinopoly.
December		Pachmarhi.
		Aden.
		Bellary.

The data indicate a fairly regular march southwards of the epoch of the secondary maximum corresponding to the transition from the wet to the dry season in India, which practically accompanies the rapid clearing of the skies preceding and accompanying the close of the monsoon rains.

D. The secondary minimum.—The following gives corresponding data for the secondary minimum —

Month	Number of stations at which the amplitude is a secondary minimum in the given month			
	Extra Tropical India.		Tropical India	
	Inland	Coast.	Inland.	Coast.
October . .	4	0	0	0
November	4	0	4	2
December	2	0	2	0
Total	10	0	6	2

In this case also the epoch of the minimum is a month earlier in Extra-Tropical India than in Tropical India. The mean epoch in the former area is about the end of October and in the latter the end of November, and hence in both areas occurs in the month following that of the secondary maximum.

The following arrangement of the stations according to months (for this feature) shows even more clearly than in the preceding case the southward march of the epochs of the secondary minimum parallel with that of the retreating south-west monsoon from Northern India southwards over the Bay and the Peninsula :—

Month	Extra-Tropical India.	Tropical India.
October	Lucknow	
	Dhubri . . .	
	Patna	
	Calcutta	
November	Lahore . . .	Jubbulpore
	Jaipur . .	Nagpur
	Allahabad	Rangoon
	Hazaribagh	Belgaum
		Bellary
		Madras.
December . . .	Roorkee	Pachmarhi
	Deesa	Aden.

The mean value of the amplitude of the secondary maximum for eighteen stations in India is ·03825", and of the secondary minimum at the same stations is ·03665", a difference of only ·00160" which hence gives a mean value of the amplitude of this secondary oscillation.

The comparison instituted in the preceding five pages has hence confirmed the conclusions given in page 338 and more especially the general inference that the annual variation of the amplitude of the second component runs parallel with, and is due to, the annual variation of the mass absorption of radiation by the atmosphere.

An important point is suggested by the examination of the curves given in Plates LXV, LXVI and LXVII showing the annual variation of the amplitude of the second component. They belong to at least two types, a simple type (with one maximum and minimum and large amplitude) exhibited by Bombay, Cottack, Kurrachee and Poona and a more complex type having two or more maximum and minimum values. The first type belongs to stations on or near the coast, the second to stations in the interior and becomes more marked in its contrast to the first type for stations further into the interior The most complex curves are those for Jaipur and Lahore. *It is hence evident that the second component depends to some extent upon local, physical or geographical conditions.*

It will be seen that the greater part of the argument of the preceding twelve pages is independent of the character of the actions accompanying the absorption of heat by the atmosphere and producing the diurnal oscillation of pressure. It simply asserts that whatever that action (*and any change directly depending on it*) may be, it will be an absolute maximum in April or May when direct solar absorption is a maximum and an absolute minimum in the height of the rainy season when direct solar absorption is a minimum There will also be a secondary minimum when solar absorption in the dry season is a minimum and an intermediate maximum, somewhat irregular in its occurrence, due to the variability of the period of termination of the rainy season in different parts of India. There is hence an annual variation in the amount of absorption, greatest during the cold weather and decreasing to the end of the hot dry weather in May. As it depends on two factors varying inversely in their effect, (*viz.*, the decrease due to increased elevation and the increase due to the greater length of day) the variations will be confined within narrow limits in the dry season, more especially as variation of each of these within the tropics is confined within narrow limits. Calculation shows that the effect of the increase in the length of the day will be greater in January and February than the decrease due to the increasing elevation of the sun. Hence the maximum diurnal absorption of energy will not be at the time of lowest elevation of the sun in India but probably about two months later, *i.e.*, in February or March, more especially as the absorption will be greater with the increase of dust in the atmosphere which in Northern India increases rapidly in amount after the termination of the cold weather rains The amount increases largely from February to April or May. It is so great in the latter month as to almost completely obscure the sun even on absolutely cloudless days. This latter condition or action hence may tend to delay the maximum to March or April.

The variation of the total absorption will evidently be much less marked in the Peninsula than in Northern India as the two factors of variation are much smaller in amount.

A rough calculation shows that the ratio of the amount of the solar energy of radiation which passes into or is intercepted by the atmosphere over a given area in Upper India in May or June (the height of the hot weather) to that intercepted in January is approximately 2 to 1.

A similar calculation gives for the corresponding ratio in the southern half of the Peninsula 3 to 2. It is not as yet possible to give corresponding figures for mass absorption.

Surface absorption of energy.—The second large action to be considered is the absorption of heat by the lowest layers of the atmosphere in contact with the earth's surface by the processes of conduction and convection. It is not necessary at the present stage of the enquiry to study the actual processes or actions. It is sufficient to state that by these processes energy (degraded solar radiation) is communicated from the earth's surface to the superjacent air, and that the amount thus communicated is probably large—as large as, if not larger than, the energy absorbed directly during the transmission of the solar radiation through the atmosphere. In the latter case, the energy is communicated directly and immediately to the whole mass, resulting probably in a general slow mass movement of expansion with collateral horizontal movements. In the former case the energy is communicated directly only to the lowest layer and probably passes very rapidly through the potential to the kinetic stage. The movements thus exhibited are in slight part expansive, but are chiefly convective in character with the accompanying horizontal movements in the lower and upper strata

Seasonal variation of surface absorption of energy.—This absorption of terrestrial surface energy (if it may be so termed) per diem will evidently be smallest in India in December and January, depending as it does on the length of the day and the elevation of the sun. It will be greatest in the hottest and driest months of the year, *i.e.*, in April, May or June, and the maximum effect will be a month or two later in Upper India than in the Deccan and Southern India. The action will be comparatively small in the rains, as the solar radiation which falls on the earth's surface is in the regions of heavy and frequent rain small in amount (due to the thick curtain of cloud which protects it from the direct solar heat action) and is also chiefly utilized in evaporating the surface water and moisture. There will hence be a marked contrast between the amount and effect of this action in the dry and wet seasons, and the contrast will be most strongly exhibited in regions in which the contrast between the dry and rainy seasons is most pronounced (*i.e.* the Gangetic Plain, Central India and the Central Provinces) and will be feeble in the regions of comparatively slight rain during the south-west monsoon, including Sind, Rajputana and the West and Central Punjab. There will hence be a minimum of action due to these surface conditions (generally in July—the month of most general and heaviest rain). Finally this action will have a more or less considerable increase at the termination of the rains, as over a large part of the interior of India the transition from the rainy season conditions to dry weather conditions is comparatively abrupt. There will hence be a secondary maximum shortly after this in September or October according to position following the minimum due to the rainy season conditions.

A consideration of the actions would also indicate that in the drier interior districts of North-Western India, the first minimum in the cold weather (when the solar heating action is small due to the low elevation of the sun and the shortness of the day)

would be the absolute minimum but that in the Peninsula and more especially the west coast districts, the second minimum in the height of the rains would probably be the absolute minimum.

Whence as a general conclusion, although it decreases with latitude, its variation is not chiefly dependent upon latitude, but apparently far more largely upon local conditions.

The chief feature of this action is that it depends very largely upon local conditions such as amount and depth of cloud, position in the interior or near the sea coast, proximity to hills, etc., and other conditions determining amount and periods of rainfall, etc.

A study of the data of the ground surface and air temperatures at Jaipur and Allahabad and of the charts in Plates VIII and IX illustrating the data will show the general character of the action between the ground surface and the air immediately above it. Similar data for several European stations and the chief inferences suggested by the data will be found in Hann's Meteorology, pages 50 to 55. These results agree closely in general character with those given in pages 51 and 52 of the present memoir, the chief of which may be repeated for immediate reference:—

(1) The ground surface temperature is above that of the air temperature in the shade four feet above the ground during a portion of the day, varying in Northern India from about eight hours in December to twelve hours in May and thirteen hours in July.

(2) The ground surface temperature is below the air temperature for a diurnal period of about sixteen hours in December to twelve hours in May and eleven hours in July (representative of the hot weather and rains).

(3) The day or maximum differences of temperature are large, increasing in amount from December or January to April or May when the maximum differences (averaging about 43°) are nearly twice as large as in December (20°) in the latitude of Jaipur. These large differences give rise to vigorous convective movement.

(4) The night differences are small compared with the day differences and are nearly constant in amount during the greater part of the night, averaging so far as can be judged from the Jaipur data, 1° in the height of the rains, 8° in the hottest season (April or May) and 8° in the cold season (December). These differences give rise to a slow settling down or contraction of the superjacent air, accompanied with very feeble horizontal movement except under certain local conditions such as obtain chiefly in hill districts and the adjacent plains and in coast districts and the adjacent sea areas.

(5) The annual variation of the difference of the ground surface and air temperatures is similar in form to that of the annual variation of the amplitude of the first component of the pressure variation as is at once seen by comparing the curve Fig. 7, Plate VIII, representing the annual variation of the former element at Jaipur given by one year's observations, and the curves of the latter element for Bellary, Jaipur, Allahabad, etc.

(6) The annual variation of this action is not primarily a function of latitude as its intensity depends not merely on the sun's elevation but on the length of the day, and the combined effects of these give nearly the same values for the

maximum intensity in Northern India as in the Peninsula. The variation appears to depend, as already established, chiefly on local and seasonal conditions.

The following is a summary of the more important features of the annual variation of the surface absorption of degraded solar radiation energy :—

(1) The surface absorption of energy has a well-defined double annual variation at all stations in India. The annual variation is in part due to the varying elevation of the sun with season and in part to the seasonal contrasts of the wet and dry periods.

(2) There is a well-defined minimum in the cold weather (December or January) when the sun's midday elevation is least. This minimum is the absolute minimum of the year in Northern India where the variation due to the annual range of the sun's elevation is greatest.

(3) The first maximum of the year occurs in the height of the hot weather (in April or May) when the sun's elevation is greatest and the air is driest, and hence conditions are most favourable for rapid and large heating of the ground surface.

(4) The second minimum of the year occurs during the height of the rains or in the month of July over the whole of India. This is the absolute minimum of the year in Tropical India where the contrast between the dry and wet seasons is more effective than the range of midday elevation of the sun.

(5) The second maximum of the year occurs at the end of the rainy or wet season when the rapid clearing of the skies accompanies a large and rapid increase of the heating of the ground surface followed by decrease due to decreasing elevation of the sun. This change is most marked at the interior stations of Northern and Central India and the North Deccan.

Comparison of annual variation of surface absorption of energy and of the amplitude of the first component of the pressure diurnal oscillation.—One of the primary facts established by meteorology is that the rapid uptake or convective movement accompanying or giving rise to the conversion of thermal potential energy of any portion of the atmosphere into the *kinetic* energy of convective air movement is accompanied by a decrease of pressure at and near the earth's surface, the intensity of which is related to the intensity and amount of the convective movement.

The heating of the lower strata of the atmosphere is due chiefly to contact with the earth's surface.

The communication of heat by day gives rise to expansion and to convective movement or uptake. Uptake is as a rule accompanied with or followed by decrease of pressure at the earth's surface in the area of uptake, and the inverse movement of descent by increase of pressure. The communication of heat between the earth's surface and the lower atmosphere is hence periodic in character, the chief period being 24 hours. The air movement and variation of pressure accompanying this action will also be periodic and hence be a simple or complex variation of 24 hours' fundamental period. This at once suggests that the first or 24 hourly *component may chiefly or primarily represent the* effect of this periodic action.

This question is discussed in the following pages.

The following table which gives the monthly mean amplitudes of the first component in Extra-Tropical and Tropical India is given for easy reference:—

Area.	Mean monthly values of the amplitude of the first component in											
	January	February.	March.	April	May	June.	July.	August	September	October.	November.	December.
Extra-Tropical India Inland	·02262	·03301	·03150	·03591	·03731	·03277	·02615	·02758	·02899	·02769	·02505	·02513
Extra-Tropical India Coast.	·02276	·02661	·03762	·02812	·02385	·01915	·01742	·01923	·02162	·02407	·02492	·02448
Tropical India Inland.	·02754	·04177	·03580	·03585	·03484	·02292	·01615	·02061	·02473	·02617	·02558	·02335
Tropical India Coast	·02159	·02414	·02726	·02783	·02512	·01890	·01848	·01815	·02071	·02071	·01897	·01937
Mountain Crest stations	·00530	·00998	·00868	·00884	·01136	·00962	·00765	·00706	·01130	·00767	·00615	·00561
Mountain Valley stations.	·01180	·01568	·02186	·02181	·02574	·02598	·02943	·02943	·03037	·02954	·02401	·01841

The following are the more important inferences from the above data illustrating the parallelism between the time or annual variation of the amplitude of the first component and the surface absorption of energy by the atmosphere:—

(1) The amplitude varies very largely; but it is not possible to express the annual variation as a function of the latitude as it varies at stations in the same latitude very largely with seasonal and local conditions.

(2) The first or cold weather minimum of the year occurs on the mean of all stations in Extra-Tropical India in January (when surface absorption is least). It occurs in November in the coast districts of Tropical India and in December in the interior. This acceleration of this epoch is almost certainly due to the rainfall of the period in that area which tends to diminish surface absorption considerably and accelerate the minimum which, due solely to the sun's elevation, would be in January as in Northern India. This minimum is the absolute minimum of the year in Extra-Tropical India Inland.

(3) The first maximum of the year is in the height of the hot weather, in April in Tropical India and Extra-Tropical India Coast, and in May on the average in Northern India. It hence occurs at the period of greatest heating of the ground surface and of surface absorption in each of these areas. It is very variable at the hill stations (*e.g.*, Pachmarhi, Simla, Srinagar and Leh) where the local conditions vary very largely.

(4) The second minimum of the year occurs in July on the mean of all stations in Extra-Tropical India and Tropical India Inland or in the height of the rains when surface absorption is least. It is the absolute minimum of the year in Tropical India and Extra-Tropical India.

(5) The second maximum of the year is in September in Extra-Tropical India Inland and in October in Tropical India and at the coast stations in Extra-Tropical India. It is hence coincident in its epoch with the partial or complete clearing of the skies accompanying the retreat of the south-west monsoon.

(6) The cold-weather minimum amplitude is considerably smaller in amount in Extra-Tropical than in Tropical India (where it is diminished by the action of rainfall).

(7) The hot-weather maximum is on the average of all stations greater in Extra-Tropical than in Tropical India. It varies considerably in amount at different stations, but is absolutely greatest at the following stations:—

Month.	Extra-Tropical India.		Tropical India.	
	Station.	First maximum amplitude of the first component.	Station.	First maximum amplitude of the first component.
April . .	Agra . . .	·03688	Nagpur . . .	·04519
	Goalpara . .	·04694	Rangoon . . .	·04481
	Dhubri . . .	·04546		
May . .	Lucknow . .	·03818	Jubbulpore . .	·03803
	Patna . . .	·04191	Bellary . . .	·04349
	Allahabad . .	·04053		
	Deesa . . .	·04130		

(8) The amplitudes of the wet-season minima are considerably less in Tropical than in Extra-Tropical India. This again is in accordance with the general facts of surface absorption.

(9) The amplitude of the second maximum at the termination of the rains is greater in Extra-Tropical than in Tropical India. It averages ·028" in the former and ·024" in the latter area.

(10) It is very small on mountain crests and large in mountain valleys even at the same elevation, and is hence at different elevations not proportional to the actual pressure but depends upon other local conditions. These have been fully and clearly worked out by Hann and his conclusions have been generally accepted. This is in accordance with the assumption or hypothesis as it is evident that the conditions and amount of surface absorption are quite different in mountain areas from those in the level plains of Northern India and the Deccan.

(11) It is considerably larger at inland than at coast stations. The following gives data for six pairs of stations for the mean day of the year:—

Coast station.	Actual amplitude on the mean day of the year.	Inland station.	Actual amplitude on the mean day of the year.
Trivandrum . . .	·01608	Trichinopoly . .	·02859
Madras	·01980	Bellary . . .	·03254
Bombay	·01840	Poona	·02456
Rangoon . . .	·02666	Bellary . . .	·03254
Chittagong . . .	·02262	Calcutta . . .	·02595
Kurrachee . . .	·01937	Deesa	·02872

A similar contrast between coast and inland stations holds as strongly, it need hardly be stated, between the absorption of energy by the atmosphere from the earth's surface. Conduction and convective action increases from the coast stations for some distance to the drier districts of the interior.

(12) It also, as indicated by the data for Belgaum, Poona, Cuttack and Calcutta, depends on other conditions such as position with respect to land and sea winds.

(13) It appears in India to be dependent largely upon the temperature conditions of the lowest atmosphere which again are largely dependent upon local conditions as for example winds, neighbourhood to the sea or to ranges of hills, etc.

The preceding remarks have established that there is a strict parallelism between the more important features of the annual variation of the first component of the diurnal oscillation of pressure and of the absorption of heat energy by the earth's surface and its transference to the adjacent atmosphere by the accompanying large convective and other movements, more especially in the following :—

(1) The critical epochs of both occur at about the same periods of the year.

(2) The northward and southward march of the critical epochs depends on large seasonal conditions.

(3) The character of the epochs, *i.e.*, whether absolute or secondary, are coincident in time and vary similarly in time over India.

(4) The periods and amplitudes of the former are directly related to the intensity of the latter and are not chiefly a function of the latitude, but depend in part upon seasonal conditions, *e.g.*, distribution of rain, contrasts of humidity, temperature, etc., and in part upon local topographical conditions such as proximity to the sea, relation to and character of prevailing winds, etc.

Comparison for stations.—This parallelism between the two series of annual variations is further confirmed by a closer examination of the facts for individual stations.

A First or hot weather maximum.—The following gives a summary of the data showing the period of occurrence of the first maximum amplitude in India in the course of its annual variation :—

Month.	Number of stations at which the amplitude is a maximum in the given month.	
	Extra-Tropical India.	Tropical India.
February	0	2
March	0	4
April	5	4
May	6	3
June	2	0
Total .	13	13

CHAPTER IX.

CONCLUDING GENERAL DISCUSSION.

The object of the following discussion is not to work out a complete theory of the diurnal oscillation of the barometer, but to investigate the relations between the diurnal oscillation of pressure in India as disclosed by the series of observations under discussion and the diurnal variations of the other elements of meteorological observations and also to ascertain to what extent it is dependent upon the seasonal variations of meteorological conditions and upon local and geographical conditions in India.

The Indian Empire forms a fairly well-defined meteorological area, presenting massive and well-defined contrasts of seasons, and a greater variation of climatic and local conditions than perhaps any other similar area in the world. It hence, so far as I can judge, affords an excellent field for testing how far seasonal and local geographical conditions modify the amplitudes and periods of the diurnal oscillation.

The chief investigators in this branch of meteorological enquiry are Kreil, Buchan, Blanford, Hann, Cole, Curtis, Angot, Rykatcheff and Bigelow.

BUCHAN and HANN represent the two chief types of investigation in this field. Buchan in his papers on the subject deals with the diurnal oscillation as a whole and endeavours to correlate it with the actual pressure changes due to temperature and air movement, which more or less co-operate and act together. It seems to me that Buchan's method is necessary for a thorough grasp of the subject, more especially the connection between air movement and pressure.

The other type of investigation, adopted by Hann, is to employ the method of harmonic resolution of the oscillation into harmonic components; to consider these separately, and to endeavour to assign these components to separate and independent actions. This is perfectly legitimate under two points of view:—

(1) If the actions are independent, and also differ considerably from the free period of oscillation of the atmosphere, so that the wave movements thus initiated will be practically proportional in amplitude to the causes.

(2) If any one of them agree closely in period with that of the free atmosphere, so that there should be an accumulation of effect due to the general principle utilized in various ways and thus enunciated by Lord Kelvin, Routh, Donkin and others, *viz.*, the amplitude of any component of a forced vibration will be large if its period coincide with that which would belong to a component of the natural vibration or there will be forced vibrations of large amplitude if amongst the components of the obligatory vibration there exist any with periods equal to those of the natural vibration.

It appears to be desirable to give a summary of the results of the investigations of Buchan and Hann for reference in the following discussion. They give the most important results of the two types of investigation in this subject. A summary is also given of Curtis's investigations as they are probably based on the longest and most exact series of observations that have as yet been utilized for the discussion of the diurnal oscillation of pressure.

(1) BUCHAN.—Dr. Buchan has dealt at considerable length with this subject. His chief contributions are to be found in his paper "On the diurnal oscillation of the barometer Part I," read before the Royal Society of Edinburgh and published in Vol. XXVII of the

The absolute maximum occurs on the mean of all stations in Tropical India in April and in Extra-Tropical India in May. The data indicate a northward movement in time of the epoch, corresponding with the movement of the greatest surface absorption.

This is shown more conclusively by the following data:—

Month.	Extra-Tropical India.	Tropical India.
February		Trivandrum.
		Agustia.
March		Trichinopoly.
		Poona.
		Cuttack.
		Chittagong.
April	Calcutta	Bombay.
	Hazaribagh	Belgaum.
	Dhubri	Rangoon.
	Goalpara	Nagpur.
	Agra	
May	Deesa	Bellary.
	Allahabad	Pachmarhi.
	Patna	Jubbulpore.
	Lucknow	
	Jaipur	
	Simla	
June	Roorkee	
	Lahore	

The preceding list indicates that the time of occurrence of the maximum epoch of the first component is delayed in advancing northwards from South India to the Punjab, the northward march being parallel in point of time with the northward advance of the intensity of solar action on the ground surface and the lowest atmospheric strata.

This maximum (*i.e.*, the hot weather maximum) is the absolute maximum at the great majority of stations, the only exceptions being the following:—

Kurrachee	·02327 in December.
Srinagar	·03540 in October.
Leh	·04665 in September.
Sibsagar	·03758 in August.
Aden	·04851 in August.
Madras	·03074 in July.

These exceptions, however, conform with the general rule as, so far as can be judged from the very imperfect available data, the months of maximum amplitude are also the months of greatest absorption of solar radiation by the ground surface at four at least of these stations.

B. Secondary maximum at the end of the rainy season.—The following table gives a summary of the data for the epochs of the secondary maximum which occurs about the termination of the rains :—

Month.	Number of stations at which the amplitude is a secondary maximum in the given month.	
	Extra-Tropical India.	Tropical India.
August	2	1
September	9	4
October	1	3
November	0	3
December	0	2
Total .	12	13

This maximum is feebly marked at most stations. It occurs generally in September in Northern India and from September to November in Tropical India and shows a fairly well defined southward progression.

The following gives a list of the stations arranged according to the months of occurrence of this maximum :—

Month.	Extra-Tropical India.	Tropical India.
August	Agra	Aden.
	Lahore	
September	Hazaribagh	Trivandrum.
	Deesa	Agustia.
	Allahabad	Trichinopoly.
	Patna	Bellary.
	Goalpara	
	Lucknow . . .	
	Jaipur	
	Roorkee	
	Simla	
October	Dhubri	Belgaum.
		Rangoon.
		Chittagong
November		Bombay
		Poona.
		Nagpur
December		Cuttack.
		Jubbulpore.

This maximum is either absent or very feebly marked at the following stations :—

Calcutta.	Kurrachee.
Pachmarhi.	Srinagar.

This maximum occurs generally in September in Northern India and from October to December in the Peninsula, and hence concurrent with the clearing of the skies at the termination of the south-west monsoon rains, and its epoch hence runs parallel with that of the retreating south-west monsoon and is earliest in Northern and latest in Southern India. It also varies very considerably in the Peninsula as might be expected from the conditions of the occurrence of cloud and rain in that area, and the prolonged and slow retreat of the south-west monsoon in the Bay and Peninsular area.

C. First or cold weather minimum.—The following gives data for the minimum in the cold weather :—

Month.	Number of stations at which the amplitude is a minimum in the given month.	
	Extra-Tropical India.	Tropical India.
November	0	4
December	1	7†
January	12*	3
February	2	0
Total .	15	14

* Absolute minimum. † Secondary minimum.

It occurs at the great majority of stations in Northern India in January. It is more variable in its occurrence in the Peninsula, ranging between November and January. The following gives the distribution of stations by months :—

Month	Extra-Tropical India.	Tropical India.
November	Hazaribagh	Trivandrum. Agustia. Bellary. Rangoon.
December		Trichinopoly. Madras. Belgaum. Poona. Bombay Nagpur. Pachmarhi.

Month.	Extra-Tropical India.	Tropical India.
January	Deesa	Cuttack.
	Allahabad	Chittagong
	Patna	Jubbulpore.
	Dhubri	
	Goalpara	
	Lucknow	
	Jaipur	
	Agra	
	Simla	
	Lahore	
	Srinagar	
	Leh	
February	Sibsagar	
	Roorkee	

This minimum occurs in Northern India, almost without exception, in January when the heating of the ground by the solar radiation is least, due to the low elevation of the sun and the decreased length of the day. The minimum at stations in the Peninsula occurs under similar conditions, but these are more variable, due to the solar action being largely and irregularly interfered with by the presence of frequent cloud, and by occasional to frequent heavy rain.

D. Second or wet season minimum.—The following gives corresponding data for the minimum during the rainy season :—

Month	Number of stations at which the amplitude is a minimum in the given month.	
	Extra-Tropical India	Tropical India.
April	0	1
May	0	1
June	1	3
July	10	6
August	4	3
Total	15	14

Whence the absolute minimum is on the mean in both areas in July (the height of the rains and the period of the greatest and most general cloud.) There is a slight

delay in Upper India where August is frequently the month of greatest cloud. The variation in the epoch of this minimum is very slight. The following gives data showing the progression of the epoch with time from south to north :—

Month.	Extra-Tropical India.	Tropical India.
April		Agustia.
May		Madras.
June	Sibsagar	Trivandrum.
		Rangoon.
July	Hazaribagh	Trichinopoly.
	Deesa	Bellary.
	Kurrachee	Belgaum.
		Poona . . .
	Allahabad	Bombay . .
	Patna	Chittagong.
	Dhubri	Pachmarhi.
	Goalpara	Jubbulpore.
	Lucknow	
	Agra	
	Lahore	
August	Calcutta	Cuttack.
	Jaipur	Nagpur.
	Roorkee	
	Simla	

The general occurrence of this phase over Northern India in July and the northward march of the epoch from the extreme south of the Peninsula in April to the Central Provinces and the Gangetic Plain in July are very significant facts and in full accord with the assumption.

The most noteworthy fact is that this minimum occurs during the height of the monsoon rains, when there is much cloud and frequent rain, and hence when the heating of the ground and the lowest air stratum is a minimum, and the meteorological conditions in India more or less markedly resemble those obtaining over open seas in the same latitudes.

The absolute minimum of the year occurs in the higher latitudes in India, *i.e.*, over the whole of North-Western India (including the Gangatic Plain, Central India, Rajputana and the Punjab) in the month of January and the secondary minimum in the rains. The contrast between the values of the two amplitudes increases with increasing latitude, and is hence strictly parallel with the variation of the terrestrial absorption of solar radiation and with convective action.

Over the remainder of India, (*i.e.*, North-Eastern and Tropical India and Burma) the absolute minimum is during the rainy season and the secondary minimum in the cool and dry season. The following gives data in illustration :—

Station.	Absolute minimum amplitude (*a*).		Secondary minimum amplitude (*b*).		Ratio of *b* to *a*.
	Month of occurrence.	U_1.	Month of occurrence.	U_1.	
		"		"	
Lahore	January	·01443	July	·03322	2·3
Agra	"	·02101	"	·02786	1·3
Jaipur	"	·01732	August	·02329	1·4
Lucknow	"	·02138	July	·02395	1·1
Dhubri	"	·03192	"	·03219	1·0
Patna	"	·02534	"	·02503	1·0
Deesa	"	·02179	July & August	·02357	1·1
Jubbulpore	July	·02087	January	·02452	1·2
Nagpur	August	·02068	December	·02676	1·3
Cuttack	"	·01754	January	·02977	1·7
Bombay	July	·00810	December	·02010	2·5
Poona	"	·00496	"	·02865	5·8
Belgaum	"	·00545	"	·01690	3·1
Bellary	"	·02248	November	·02851	1·3
Rangoon	June	·01449	"	·02406	1·7

It is a very significant fact that the absolute minimum amplitude of the first component occurs almost invariably in Northern India in the cold weather and in the Peninsula in the rainy season. There is hence an exact correspondence between the periods of greatest and least absorption of energy by the atmosphere from the earth's surface (A) and the epochs of the maxima and minima amplitudes of the first component (B), as shown below :—

Phase.	Epoch for	
	A	B
First minimum	December or January.	January.
First maximum	April to May	April.
Second minimum	July	July.
Second maximum	September or October	September.

This correspondence is almost a sufficient proof that the first component is mainly an effect due to the air-movement initiated by the heating of the lower atmosphere by contact with the earth's surface. This is confirmed by the variation of the epochs of the maxima and minima amplitudes in different seasons in different parts of India as established by the preceding discussion.

The parallelism between the epochs of the action and of the phases of the first component is exact in every respect. There is complete correspondence between what may be termed the periods of the phase or epochs of cause and effect over the whole Indian area.

It may hence be fairly assumed that the first component or element of the diurnal oscillation represents chiefly the effect of the solar radiation absorbed by the earth and given up in a degraded form to the atmosphere, the energy being redistributed by means of convective and other movements. This action of interchange of energy between the earth's surface and the atmosphere is periodic, of 24 hours. The resultant transfer is from the earth to the atmosphere during the day and from the atmosphere to the earth during the night hours. It is not possible to give an exact mathematical expression for it, but if it were developed by Bessel's method it is very probable that, in addition to a 24 hourly component of large amplitude, there would be sub-components or harmonics of shorter periods. The first component of the diurnal oscillation hence probably does not represent solely and entirely the effect of the action indicated.

Conclusions from preceding discussion (pages 332 to 358).—The preceding has shown a striking parallelism between (1st), the annual variation of the first component of the Besselian resolution of the diurnal variation of the barometer and the surface absorption of energy by the atmosphere; and (2nd) between the annual variation of the second component of the Besselian resolution of the diurnal pressure oscillation and the mass absorption of energy by the atmosphere. The parallelism is so exact as to afford a very strong presumption in favour of the following conclusions :—

(1) *The first component of the diurnal oscillation is mainly due to actions connected with the absorption of energy in the lowest atmospheric strata in contact with the earth's surface* (i.e., to surface absorption).

(2) *The second component is mainly due to actions connected with the absorption of radiation (chiefly solar) in its passage through the atmosphere* (i.e., to mass absorption).

Independence of first and second components of the diurnal pressure oscillation.—The discussion of these two actions has indicated clearly that they are entirely different from and independent of each other and that the changes of pressure due to these actions are effected by different kinds of air movement. The movement due to mass absorption is mainly one of general expansion and contraction accompanied by slight horizontal movements and that due to surface absorption is mainly convective in character, *i.e.*, local, vertical or convective movements and vortex whirls with the accompanying general horizontal movements.

As the actions are independent of each other and have different laws of annual and of diurnal variation (although both in part are the result of seasonal conditions) the first and second components of the diurnal pressure oscillation should, on the assumption given

above, be almost, if not quite, independent of each other. One of the most remarkable features of the diurnal oscillation pointed out by all investigators who have analyzed the diurnal oscillation by the Besselian process is the absence of relation between the first and second components.

The assumption or hypothesis (given as a conclusion of the preceding discussion in page 339) also accounts for the magnitude of the second component as compared with the first, as it makes them depend upon variations of the absorption by the atmosphere of the energy of solar radiation, the total amount of which in the case of the mass absorption of solar radiation is, according to Langley, at least 33 per cent (according to another estimate 40 per cent.) of the total solar radiation and in the case of the surface absorption is (taking into consideration irregular reflexion at the earth's surface, absorption by vegetation etc.) most probably not more and probably less than that percentage amount.

The following gives a few of the more important points of contrast between these two elements or components of the diurnal pressure oscillation:—

(1) The amplitudes of the first component are very small for insular or coast stations and are large for continental stations, whereas the amplitudes of the second component are large and are practically the same in amount over continents and oceans in the same latitudes.

(2) The amplitudes of the first component depend to a very large extent on local conditions whereas those of the second component vary slightly with local conditions and are mainly a function of latitude.

(3) The amplitudes and epochs of the first component at stations in mountain valleys and on mountain ridges vary very largely from each other and also from those of plains stations in the same latitudes and under similar general meteorological conditions and also very largely from the corresponding elements at neighbouring stations in open plains. On the other hand, the amplitudes of the second component at mountain stations are approximately proportional to the actual pressure and the critical epochs identical with those at neighbouring plains stations.

(4) The critical epochs of the second component vary within much narrower limits with latitude and season than those of the first component.

(5) The amplitude of the first component in the course of the year varies much more largely with latitude and season than that of the second component.

(6) The amplitudes of the first and second components have a double variation of oscillation in the course of the year. The primary oscillation in the case of the first component depends, more especially in Northern India, upon the contrast between the cold and hot seasons, and in the case of the second component upon the contrast between the dry and wet seasons. They hence depend upon or are related to different seasonal conditions.

(7) The amplitudes of the secondary oscillation of the annual variation of these elements are much more pronounced in the case of the first than the second

component, the former being on the average twelve times as great as that of the second. The following gives data for six stations in illustration :—

Stations.	Amplitude of secondary oscillation.	
	First component.	Second component.
	"	"
Madras	·00502	·00090
Rangoon	·01146	·00019
Nagpur	·01404	·00047
Calcutta	·01037	·00227
Deesa	·00682	*Nil*
Lahore	·00538	·00080

Further confirmation of the hypothesis—The following conclusions should be kept carefully in mind throughout the present discussion :—

(1) The actual pressure variation is a residual or differential effect.

(2) The total air pressure in India usually adjusts itself rapidly to the local conditions. Large local differences of aqueous vapour pressure and of temperature and of changes of these elements may obtain over the land at stations within 50 or 100 miles from each other and yet the resultant diurnal oscillation at these places of very different meteorological conditions is usually almost identical in character and amount.

(3) It is only when the local conditions and variations of conditions become large and massive that we find large variations of type. Amongst the chief variations of conditions in India modifying the character of the diurnal pressure oscillation are the following :—

(*a*) Transition from land to sea.

(*b*) Variations due to alternating land and sea breezes.

(*c*) Variations due to contiguity to extensive mountain masses and resulting from the local atmosphere movements in these areas.

Continental and maritime types.—According to the explanation or hypothesis advanced, the action and resulting diurnal variations of pressure due to mass absorption are similar in amount and character over continents and oceans in the same latitudes, whereas those due to surface absorption are very slight over oceanic surfaces and are large in the interior of continents and increase rapidly in amount in passing across the coasts into the interior.

Hence the diurnal variation at sea consists mainly of a semi-diurnal oscillation and of sub-components, whereas over the land it is the combination of two independent and large components with sub-components, *viz.*, a semi-diurnal harmonic oscillation as over the oceanic surface and a diurnal harmonic oscillation increasing in importance and amplitude as we proceed from the coast districts to the dry interior of the continent (with the respective sub-components).

The hypothesis or explanation accounts satisfactorily not only for the contrast between the maritime and the continental types of the diurnal oscillation but also fo the approximation of the diurnal pressure oscillation over the greater part of India to the maritime type during the height of the south-west monsoon

Two additional confirmations.—This hypothesis advanced to account for the elements or components of the diurnal pressure or oscillation is further confirmed by various other considerations or comparisons of which the two following appear to be the most important:—

(A). The cause, *viz.*, the absorption of energy transmitted from the sun to the earth's surface and thence communicated to the atmosphere by the process of convective movements varies very considerably through the year. Its measure is, for comparison purposes, from one point of view the total amount received per diem, and from another, the greatest intensity of the action during the day.

It is evident that, taking into consideration the intensity of the action and the length of the day, the measore of the maximum total diurnal absorption will differ little in *different parts of the interior of India during the dry season, as the conditions of humidity,* solar intensity, absorptive powers of the soil and atmosphere do not differ much in that season.

Hence it may be fairly assumed that the maximum amount of absorption will differ little in intensity in the interior but that its epochs will be earlier in the Peninsula than in Northern India and more especially North-Western India.

This is exactly paralleled by the chief features of the absolute maximum amplitudes of the first component, *viz.*, that they differ little in amount at stations in the interior of India but that the epochs are retarded with increasing latitude. The following selected data illustrate these two features fully:—

Station.	Absolute maximum amplitude of the first component.	Month of occurrence.
Trichinopoly	·03785	March.
Poona	·03548	"
Cuttack	·03738	"
Nagpur	·04539	April.
Calcutta	·03480	"
Deesa	·04130	May.
Allahabad	·04053	"
Patna	·04191	"
Lucknow	·03818	"
Roorkee	·03930	June.
Lahore	·03980	"

(B). A second noteworthy feature is that the ratios of the absolute maximum and minimum amplitudes of the first component of the diurnal pressure oscillation are roughly

Transactions of that Society, in the volume on the scientific results of the Challenger Expedition entitled "Report on Atmospheric Circulation," pages 11 to 24, and in the article "*Meteorology*" in the last edition of the *Encyclopædia Britannica* (Vol. XVI, pages 121—4).

It may be pointed out that throughout his work he discusses the diurnal oscillation as a whole and does not employ Bessel's methods of resolution into harmonic components.

The following gives the more important facts and inferences relating chiefly to, the diurnal oscillation in tropical regions (within 30° north and south of the equator) given by Dr. Buchan in his article "Meteorology" in the Encyclopædia Britannica which we believe represents his latest and most complete views on the subject.

"In the tropical belt the lines of maximum and minimum epochs run north and south, and hence the effect is that of waves advancing in a westerly direction with the velocity of the sun's apparent motion. In extra-tropical regions the lines are largely modified, chiefly in the morning maximum and afternoon minimum. The conditions of maritime stations delay and of continental stations accelerate these epochs, more especially the morning maximum epoch. The retardation of the 10 A.M. maximum is greatest in islands or insular masses near great tracts of land".

"In proceeding vertically upwards, the morning maximum occurs later (*e.g.*, at Ben Nevis at 3 P.M.). In many cases, the effects of elevation of the diurnal oscillation are similar to those of proceeding from the interior of continents to maritime and insular districts. A common feature in insular and mountain districts (*i.e.*, on summits of ranges) is that the early morning minimum is more marked than the afternoon—the contrast increasing with intensity of conditions."

The following are the more important facts upon which Dr. Buchan bases his theory of the origin and cause of the diurnal oscillation:—

(1) The oscillation occurs alike in the open oceanic surface as well as over the land surface of the world.

(2) The oscillation over the tropical regions of the Pacific and Indian oceans consists of a large day oscillation and of a smallish night oscillation, the amplitudes of which are in the ratio of about 5 : 2.

(3) The amplitude of the oscillation is greater in an atmosphere highly charged with aqueous vapour than in a dry atmosphere (in the same latitude and at the same elevation).

(4) One of the most striking facts of meteorology is the suddenness with which the barometric oscillation increases in amplitude on entering the low pressure belts of the inter-tropical regions and the rapidity with which it diminishes on entering into the high pressure regions of the horse latitudes.

(5) The amplitude of the diurnal oscillation decreases with elevation, but is greater proportionately to the whole pressure than at low levels.

(6) The amplitudes and times of occurrence of the phases of the diurnal barometric tides are subject to great modifications over the land—in point of time—due to the heating of the earth, and hence are most marked in character where insolation is strongest.

Buchan considers (3) and (4) as strong, if not conclusive, proofs that the diurnal oscillation is due chiefly to the direct absorption of solar radiation in its passage from the

proportional to the relative intensities of the diurnal heating of the surface and lower strata by the solar action It has been pointed out in a previous page that although the absolute maximum amplitudes of that component occur during similar hot weather conditions and hence during the same period in India, the absolute minima amplitudes occur in North-Western India and the remainder of India under different meteorological conditions and at different seasons of the year.

The absolute minima occur in North-Western India when the heating action of the sun is small due to its low elevation and to the shortness of the day and when also there is occasionally a considerable amount of cloud, accompanying the cold weather storms of the period As these conditions are more and more marked the further we advance northward, it would follow on the supposition advanced that the absolute minimum amplitudes of the first component would occur at stations in North-Western India during this period, that they would decrease in amount with increasing latitude and that the ratio of *the absolute maxima (which are nearly uniform in amount)* to the absolute minima would increase considerably in that area with increasing latitude.

The following table gives data which show that these inferences are in exact accordance with facts —

Station	Absolute minimum amplitude.		Absolute maximum amplitude		Ratio.
	Month of occurrence	U_1	Month of occurrence.	U_1	
		°		°	
Lucknow . . .	January .	02138	May .	03818	1 8
Agra	"	02101	April . . .	03688	1 8
Deesa		02179	May .	04130	1 9
Jaipur . . .	. .	01732	, . .	03569	2 1
Roorkee	February	01365 ?	June	·03990	2 9
Lahore	January	01443	" . .	03980	2 8

The meteorological conditions, more especially the amount of cloud and aqueous vapour pressure, do not differ largely during the dry season and their variations are inverse to each other. It is hence interesting to note that the maximum difference of temperature between the ground surface and air four feet above is very approximately twice as large in April or May as in January, and that taking into account the diurnal period of solar action the ratio of the total diurnal absorption in these months is approximately three There is hence a close correspondence between the quantitative variations of these two (*viz.*, surface absorption and amplitude of the first component) in North-Western India during the dry season as measures of cause and effect.

The absolute minima amplitudes occur in the rainy season over the remainder of India including North-Eastern and Central India, Burma and Tropical India. The contrast of conditions determining the action at these stations is between the clearness of the skies and freedom from cloud, etc, in the dry season of greatest absorption and heating of the earth's surface by the solar action on the one hand and the density of cloud, amount of rainfall, steady persistency of rain and comparative absence of sunshine in the wet or rainy season on the other hand. This contrast is most marked in the Konkan, Malabar

and the West Deccan. It is the area of least cloud and greatest serenity in the cold and hot weather months, and is also the region of heaviest and most frequent and persistent rain and of the greatest density or thickness of cloud in the rainy season months. This is paralleled by the corresponding contrast between the maximum and minimum amplitudes, as shown by the following data for the stations for which information is available :—

Station.	Absolute minimum amplitude.		Absolute maximum amplitude.		Ratio.
	Month of occurrence.	U_1	Month of occurrence.	U_1	
		"		"	
Bombay	July . . .	·00810	April . . .	·02800	3·5
Poona	" . . .	·00496	March . . .	·03542	7·1
Belgaum	" . . .	·00545	April . . .	·02634	4·8
Trivandrum . . .	June . . .	·01018	February . .	·02108	2·1
Rangoon	" . . .	·01439	April . . .	·04481	3·1

Over the remainder of India including North Eastern and Central India where the contrast is less marked, the ratios range between 1·3 and 2·0 and are practically the same under similar conditions.

Sub-components related to first and second components of diurnal pressure oscillation.—

It has been established that the first and second components differ so completely from each other in the amount and variation of their amplitudes and epochs as to be independent of each other and represent the effect of independent actions, causes or conditions and that this conclusion is generally accepted by all physicists who have dealt with the subject from this aspect. On the assumption of the explanation given, it has been pointed out that the variations of energy accompanying and producing the component variations of pressure measured by the first and second components of the Besselian resolution are not simple harmonic variations.

If this be the case, it is almost certain that the effect of their actions cannot be represented by a simple harmonic element, but that there would be sub-components in their analysis if they could be analysed separately.

In this case the first component might have residual components of 12, 8 and 6 hours and the second, of 6 and 4 hours, etc.

This hence suggests that the second component may contain a small residual element accompanying the first, and that the third component will be either independent or a factor of the expansion commencing with the first component, but independent of the second. Similarly, the fourth component may be part of the expansion of both the first and second.

Third component of the diurnal pressure oscillation.—The only possible assumptions respecting the origin of the third component are:—

(1) That it represents the effect of an independent action of eight hours period, or

(2) That it is a portion of the effect due to the causes producing the first component, which although of 24 hours period cannot be expressed as a simple harmonic function of that period.

The first of these suppositions appears to be at once barred by the statement that here is no independent physical action of eight hours period, hence a strong antecedent proof that the second conclusion or assumption is the correct one. This is confirmed by the following considerations.—

(1) The amplitude of the third component is very small, resembling in character that of a residual effect rather than the total effect of an independent cause or action. The following gives data showing its mean relation to the amplitude of the first component :—

Area	Amplitude of U_1 of year (a)	Amplitude of U_3 of year (b)	Ratio of (a to b).
	′	′	
Extra-Tropical India, Inland .	·02854	·00167	17·1
" " Coast	·02265	·00178	12·7
Tropical India, Inland . .	·02672	·00152	17·6
" " Coast .	·02057	·00142	14·5
Mountain Crest stations . .	·00764	·00095	8·0
" Valley stations .	·02323	·00260	8·9

Complete data of the amplitudes of the third component for 32 stations for each month will be found on page 310.

(2) The amplitude of the third component varies largely (relative to its actual amount) and somewhat irregularly. This is best shown by data for ten selected stations :—

Station.	Third component.		
	Absolute maximum amplitude (a)	Absolute minimum amplitude (b)	Ratio of (a to b).
	′	′	
Trivandrum	·00384	·00045	8·5
Madras	·00456	·00022	20·7
Rangoon	·00842	·00036	23·4
Bombay . .	·00660	·00070	9·4
Calcutta . .	·00834	·00131	6·4
Allahabad . . .	·00841	·00163	5·2
Nagpur	·00645	·00117	5·5
Jaipur . . .	·00849	·00130	6·5
Roorkee	·00643	·00133	4·8
Lahore	·00718	·00124	5·8
Simla	·00616	0	
Agumba . . .	·00166	·00089	1·9

The data indicate that the variability in the amount of the amplitude is very large and is larger in Southern India and Lower Burma than in Northern India. In other words, the variability is greatest where the meteorological actions are most regular and least variable.

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(3) The annual variation of the amplitude of the third component follows the same law as that of the first component with the one remarkable exception that the maxima epochs of one correspond with the minima of the other. The data for this are given in page 302 but are repeated here :—

Phase.	Epoch for		
	First Component.	Third Component.	Second Component.
Absolute maximum . . .	April . .	January . .	February or March.
Ditto minimum . .	July . .	April . .	June or July.
Secondary maximum . . .	September .	May or June	September or October
Ditto minimum . .	January .	September .	October or November

The following gives mean values of the amplitude at the critical epochs of the first and third components for the two large groups of stations in the plains of India :—

Phase.	Third component			First component.		
	Period of phase.	Mean amplitude, Tropical India.	Mean amplitude, Extra-Tropical India.	Period of phase.	Mean amplitude, Tropical India.	Mean amplitude, Extra-Tropical India.
		"	"		"	"
Absolute or primary maximum . .	January .	·00541	·00778	April or May .	·03228	·03516
" " minimum .	April .	·00154	·00172	July or January	·01710	·02265
Secondary maximum . . .	May or June	·00247	·00370	October or September.	·02374	·02761
" minimum	September.	·00146	·00177	December or July.	·02158	·02451

The preceding data establish that the critical epochs agree in all periods except the third in which the epoch of the third component is slightly accelerated over that of the first and that they are inverse in character, *i.e.*, the minimum of one corresponds to the maximum of the other in time.

The ratios of the mean amplitudes of the first and third components in Tropical and Extra-Tropical India are practically the same at these periods :—

	Third component.	First component.
	Ratio of Tropical to Extra-Tropical India.	Ratio of Tropical to Extra-Tropical, India.
January	1·4	1·1
April	1·1	0·9
May or June	1·5	0·8
September	1·2	0·8
Mean day of year	1·15	1·14

(4) The amplitudes of the first and third components are greater in Extra-Tropical than in Tropical India, in which respect these components differ from the second; as is shown by the following data.:—

Area.	Value of the amplitude for the mean day of the year of the		
	First component	Second component	Third component.
	″	″	″
Tropical India	·02399	·04136	·00147
Extra-Tropical India	·02743	·03526	·00169

It may also be noted that the relation holds not only for the mean day of year but practically throughout the year.

(5) The variability of U_3 is much greater than that of U_1 in both areas and increases with latitude, as is shown by data for the following stations in the interior:—

Station.	Amplitude of U_3 in				Ratio of maximum to minimum.
	January.	April	July.	September.	
Trichinopoly	″·00280	″·00202	″·00175	″·00081	3·5
Bellary	·00546	·00064	·00130	·00136	8·5
Nagpur	·00608	·00117	·00285	·00199	5·2
Jaipur	·008497	·00179	·00332	·00130	6·5
Deesa	·00660	·00104	·00238	·00133	6·3
Allahabad	·00841	·00163	·00359	·00181	5·2
Agra	·00700	·00277	·00408	·00197	3·6
Lahore	·00718	·00124	·00340	·00214	5·8

(6) The most remarkable feature of the third component (in which it is unique) is the large change of epoch at the time of the minimum phases. There is little change of phase in either of the two intermediate periods. The following gives data in illustration:—

Area.	Mean epochs of the Third component					
	October to March		April to August		April to September.	
	H.	M.	H.	M.	H.	M.
Extra-Tropical India, Inland	2	10	5	32	5	10
" " Coast	1	52	6	10	5	36
Tropical India, Inland	2	18	5	43	5	16
" " Coast	1	48	5	19	4	51
Mountain Crest stations	2	18	5	17	5	8
" Valley stations	2	9	3	42	3	32

The data indicate that the change occurs about the equinoxes. During the period when the sun is south of the equator and the day period of solar influence is less than 12 hours the first maximum is about 2 A.M., and during the remainder of the year when the sun is north of the equator and the day exceeds 12 hours in length, it is about 5-30 A.M. A comparison of the data also establishes that the epoch of the inversion is simultaneous with the epochs of minimum amplitudes.

The coocurrence of the critical epochs of the first and third components and other points of parallelism or correspondence and the very great variability of the amplitude of the third component indicate that that component is not a variation due to the action of independent causes but that it is chiefly what may be termed a correction to the first component, to modify a purely simple harmonic variation to an actual variation due to causes which are not simply harmonic (of 24 hours period). It is in fact a residual of a residual.

It appears to be desirable to ascertain the effect of superimposing the third component on the first in order to explain the function of the large change of phase which occurs in April and September.

In Plate LXXII, Figs. 1 to 6, are given curves representing the diurnal variation of the first and third components, and of the sum of the two at the stations of Jaipur and Allahabad for the three months of January, May and July, representative of the cold-dry, hot-dry and wet seasons.

From October to March, the first maximum of the third component is at about 2 A.M. From figures (1) and (4) the following conclusions may be deduced:—

(1) The morning maximum of the combined curve is considerably later than that of the U_1 curve.

(2) The evening minimum of the combined curve is later than in the U_1 curve.

(3) The combined curve has a slight secondary variation in the early morning and in the afternoon. An examination of the data shows that this feature is only present during months when the ratio of the amplitudes of the first to the third component is less than 4 to 1.

(4) The rate of increase of pressure in the combined curve is less than in the U_1 curve generally from 3 A.M. to 6 A.M. and is greater from 7 A.M. to 10 A.M.

(5) The rate of decrease of pressure in the combined curve is greater than in the U_1 curve from noon to 3 P.M. and is less from 4 P.M. to 6 P.M.

The curves for May and July represent the superimposition of U_3 on U_1 when the first maximum phase of the third component is at about 5 A.M. A glance at these curves at once shows that the effect of the superimposition of U_3 on U_1 is much less marked in these months than in January. The chief effects in this case are:—

(1) The first maximum in the combined curve is roughly about an hour earlier than in the U_1 curve.

(2) The afternoon or evening minimum is slightly earlier in the combined curve than in the U_1 curve.

The effect of the superimposition of the third upon the first component is to retard the morning maximum by an amount depending on their relative amplitudes in the period October to March, and to accelerate it during the remainder of the year from April to September.

It would hence appear that the third component is in part a correction or addition to the diurnal or 24 hourly component due to the varying length of the day and is hence opposite in its action or sign according as the diurnal period of the solar action is greater or less than 12 hours.

Fourth component.—It has been pointed out that there are large and massive actions of diurnal and of semi-diurnal period and that the six-hourly component may represent or be due to either of these or to both of them, and if so that its further resolution from this point of view is at the present not possible.

The amplitude of the fourth component is small for all seasons and for all stations in India, but it varies largely and somewhat irregularly throughout the year, the only common feature being a maximum in the cold weather and a minimum usually in the rainy season but somewhat irregular in the period of its occurrence.

The following table gives the monthly values of the amplitudes of the fourth component for six large groups of stations in India for comparison :—

Area.	Mean amplitude of the fourth component in											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	"	"	"	"	"	"	"	"	"	"	"	"
Extra-Tropical India, Inland .	·00300	·00132	·00095	·00098	·00137	·00110	·00112	·00106	·00115	·00149	·00191	·00301
Extra-Tropical India, Coast .	·00273	·00114	·00065	·00087	·00104	·00072	·00075	·00159	·00087	·00169	·00178	·00303
Tropical India, Inland .	·00184	·00171	·00091	·00103	·00095	·00073	·00070	·00089	·00130	·00109	·00177	·00204
Tropical India, Coast .	·00215	·00216	·00160	·00112	·00071	·00081	·00054	·00102	·00108	·00174	·00149	·0018[illegible]
Mountain Crest stations .	·00173	·00105	·00086	·00076	·00074	·00072	·00064	·00098	·00121	·00099	·00103	·00187
Mountain Valley stations .	·00342	·00195	·00116	[illegible]	·00117	·00131	·00105	·00124	·00099	·00138	·00171	·00247

In the plains of India the amplitude of the fourth component varies between ·0005" and ·003" and is hence very small in amount, more especially when compared with the values of the amplitudes of the first and second components. It is hence most probably a residual of a residual effect.

The annual variation is large relatively to the actual amount and is somewhat irregular. There is a fairly well defined maximum in December (in January in the Tropica India Coast area) and an equally well defined minimum in the rainy season (in July) on the average of all stations. The variations are small from May to September and the actual data indicate that the epoch of this minimum ranges between June and August. The data also suggest that there are no well defined general secondary maximum and minimum values. Notwithstanding the agreement of period it appears to me very doubtful whether it can be assumed that the annual variation of the fourth component is in part due to variation of distance of the sun which is least at perigee in December and greatest in apogee about the end of June.

The following table gives the epochs of the absolute and secondary maximum and minimum values in the annual variation of the amplitudes of the four components of the diurnal pressure oscillation in India :—

Phase.	First component.	Second component.	Third component.	Fourth component.
Absolute maximum	April or May	March	January	December or January
Absolute minimum	July	July	April	July
Secondary maximum	September	October	May or June	?
Secondary minimum	January	November	September	?

The fourth component agrees with the second in the absence or insignificance of the secondary oscillation and with both the first and second in the occurrence of the absolute minimum values in the height of the rains. It differs from both in having its absolute maximum in the cold weather but in this feature resembles the third component.

The amplitude of the fourth component on the whole decreases with latitude, and also with elevation, in which respects it agrees more closely with the second than the first component.

The epoch of the first component.—The comparison of the law of annual variation of the surface absorption of heat energy by the atmosphere and of the first component has indicated that they are closely related as cause and effect.

It has been shown that there is a slow but fairly uniform transfer of energy from the lower atmosphere to the ground surface during the night. This accompanies cooling of the air, generally mass descent or contraction of the mass of the atmosphere, together with a slight influx above which increases the super-incumbent mass, and hence the pressure of the lowest stratum. Hence the general effect of this night action or air movement is to give a slight but continuous increase of pressure so long as the movement continues.

Conditions change immediately after sunrise. The excess of solar radiation is absorbed at first very slowly, but in increasing amount until about mid-day and thence decreases until sunset. A large portion of the energy is given up to the atmosphere. The lowest strata are rapidly heated and convective movements are initiated which increase in intensity and volume until 2 or 3 P.M. in the lower strata and 3 or 4 P.M. in the middle strata. This vigorous uptake is accompanied and followed by outflow above together with similar influx below (less in amount). The mass of super-incumbent air hence decreases from shortly after sunrise and so long as the convective movement proceeds and hence also the atmospheric pressure near the earth's surface will decrease from about or shortly after sunrise until about sunset.

The complete action will probably extend through a greater depth of atmosphere in the first stage (*i.e.*, during the night hours,) than the second stage (during the day hours). The influx in the first stage will occur in the upper strata, whilst the outflow in the second stage probably not above the middle atmospheric strata.

The preceding argument hence indicates that this change of pressure will be of 24 hours period, and that the maximum will probably be about or shortly after sunrise, and the minimum slightly before or about sunset.

The action is not simply periodic for two reasons.

1st.—The night action is different in character, intensity and amount from the day action.

2nd.—The length of the day action varies from about 11 hours in the cold weather (December and January) to about 13 hours in May and June in Northern India, and differs slightly in amount in Extra-Tropical and Tropical India.

The following gives for immediate reference and comparison the more important features of the maximum and minimum epochs in the diurnal variation of the first component.

(1) The epoch is later than the mean of the year from January to May and earlier during the remainder of the year. The following gives data for the two large divisions of India:—

	Extra-Tropical India.			Tropical India.		
	Month.	A.M.	Variation from mean of year.	Month.	A.M.	Variation from mean of year.
			H. M.			H. M.
Latest epoch . .	February . .	8 2	+0 38	February . .	6 57	+0 42
Earliest epoch . .	July . . .	6 41	−0 40	July . . .	5 42	−0 33

The epochs are latest when the days are shortest and earliest when days are longest.

(2) The retardation and acceleration are largest in amount at the most northerly stations. The following gives corresponding data for three stations, *viz.*, Jubbulpore, Jaipur and Lahore:—

Station.	Lat. N.	Latest epoch.	Month of occurrence.	Retardation on mean of year.	Earliest epoch.	Month of occurrence.	Acceleration on mean of year.
	°	H. M.		H. M.	H. M.		H. M.
Jubbulpore . .	23	7 41	March . .	0 31	6 28*	June . .	0 42
Jaipur . . .	27	8 56	February .	1 1	7 16	" . .	0 39
Lahore . . .	32	9 36	" .	1 5	8 7*	July . .	0 34

* Secondary maximum epoch.

The data indicate that there is considerable irregularity depending probably upon local conditions but that on the whole there is a tendency to a larger range of variation with increasing latitude which is in accordance with the assumption :—

(3) The retardation of the epoch in Extra-Tropical India increases with latitude a shown below :—

STATION.	Mean day of year.	
	H.	M.
Jubbulpore	7	10
Jaipur	7	55
Lahore	8	31

An examination of the data for stations in corresponding latitudes in other parts of the world (given in Dr. Hann's "Untersuchen über die Tägliche Oscillation des Barometers") appears to indicate that this acceleration is much more marked in southern than in northern latitudes.

The following gives data for each month showing that this inference holds throughout the whole year :—

MONTH.	MAXIMUM EPOCH OF U_1 OF PRESSURE AT					
	Jubbulpore Lat. 23°N.		Jaipur Lat. 27°N.		Lahore Lat. 31½°N.	
	H.	M.	H.	M.	H.	M.
January	7	38	7	55	8	20
February	7	40	8	56	9	36
March	7	41	8	27	8	28
April	7	32	8	14	8	22
May	7	23	7	56	8	32
June	6	28	7	16	8	30
July	7	2	7	32	8	7
August	7	17	7	22	8	32
September	6	21	7	37	8	34
October	6	51	7	46	8	38
November	7	0	8	0	8	4
December	7	0	8	2	8	28
Mean . . .	7	10	7	55	8	31

son through the earth's atmosphere and before reaching the earth. In anti-cyclonic regions the absorption will be least effective in raising the temperature of the air or the absorption will be small in consequence of the prevailing dryness of the atmosphere, whereas in low pressure belts, more especially in the equatorial belts of great humidity, the atmosphere will be largely heated by the sun's rays as the absorption of the solar radiation will be a maximum.

Dr. Buchan hence bases his explanation on the principle that the diurnal oscillation of pressure is primarily due to the direct absorption by the air of the energy of solar radiation, and that the amount of this absorption *varies* very considerably with the hygrometric conditions of the air, absorption increasing with increasing humidity, absolute and relative. He considers that this factor alone obtains over the oceanic surfaces, and hence assumes that it is also the primary factor over the land surfaces, but that it is supplemented in the latter case by the heating of the land surface, which varies very largely under different conditions, whence arises the variability of form or character of the diurnal oscillation on land, more especially when contrasted with its invariability in the open oceans, or to quote Dr. Buchan's own words "the fact indicates clearly that the diurnal oscillation is not primarily caused by the heating and cooling of the earth's surface by solar and terrestrial radiation and by the effects which follow these diurnal changes in the temperature of the surface. It is primarily caused by the direct and immediate heating of the atmosphere by solar radiation and cooling, and by nocturnal radiation to the cold regions of space of the molecules of the air and its aqueous vapour. These changes of pressure due to temperature are instantly communicated through the whole atmosphere from its lowermost stratum resting on the earth's surface to the extreme limit of the atmosphere. There are local peculiarities; but it is particularly to be noted *that the barometric oscillations are independent of any change of temperature of the floor on which the atmosphere rests.*"

The following also gives in Dr. Buchan's words his complete statement of the various causes and actions contributing to the double diurnal oscillation (*vide* Encyclopædia Britannica, Vol. XVI):—

"If the temperature of the whole of the earth's atmosphere were raised, atmospheric pressure would be diminished, for the simple reason that the mass of the atmosphere would thereby be removed to a greater distance from the earth's centre of gravity.* Quite different results, however, would follow if the temperature of only a section of the earth's atmosphere were simultaneously raised, such as the section comprised between longitude 20° W. and 60° W. The immediate effect would be an increase of barometric pressure, owing to expansion from the higher temperature; and a subsequent effect would be the setting in of an ascending current more or less powerful, according to the differences between the temperature of the heated section and that of the air on each side. These are essentially the conditions under which the morning maximum and afternoon minimum of atmospheric pressure take place.

"The earth makes a complete revolution round its axis in twenty-four hours, and in the same brief interval the double-crested and double-troughed atmospheric diurnal tide makes a complete circuit of the globe. The whole of the diurnal phenomena of the atmospheric tides are therefore rapidly propagated over the surface of the earth from

* The amount would probably not exceed three or four thousandths of an inch.

(4) The epochs are in all months earlier in Tropical than in Extra-Tropical India. The following gives data illustrating this feature :—

Month.	Mean maximum epoch of U_1 for pressure in				Difference.	
	Extra-Tropical India.		Tropical India.			
	H.	M.	H.	M.	H.	M.
January	7	42	6	44	0	58
February	8	2	6	57	1	5
March	7	53	6	56	0	57
April	7	58	6	48	1	10
May	7	47	6	24	1	23
June	7	0	5	44	1	16
July	6	44	6	1	0	43
August	6	55	5	58	0	57
September	6	53	5	42	1	11
October	7	24	5	50	1	34
November	7	19	5	51	1	28
December	7	16	6	0	1	16
Mean of year	7	24	6	15	1	9

The mean epoch of the maximum is 6-15 A.M., or very shortly after mean sunrise in Tropical India and 7-24 A.M. or upwards of an hour after mean sunrise in Extra-Tropical India. The epoch is on the mean day of the year upwards of an hour later in Extra-Tropical than Tropical India.

The differences average $1\frac{1}{4}$ hours in the dry season and are absolutely greatest in October, November and May when they are nearly $1\frac{1}{2}$ hours in average amount. They diminish to nearly three quarters of an hour in the height of the rains (July and August).

(5) The epochs are greatly delayed at stations on mountain ridges. The following gives an estimate of the retardation for every alternate month at Pachmarhi and Simla, the only stations for which data are available :—

Month.	Approximate retardation over plain stations in similar latitude.			
	Pachmarhi.		Simla.	
	H.	M.	H	M.
January	1	18	3	40
March	1	4	5	17
May	0	39	2	52
July	0	48	0	46
September	0	47	2	51
November	1	38	2	59
Mean day of year	1	6	3	16

(6) The epochs are, on the other hand, accelerated in mountain valleys. Data are given for Leh and Srinagar which are examples of stations in closed valleys :—

MONTH	ACCELERATION.			
	Srinagar		Leh	
	H.	M.	H.	M.
January	−3	7	1	46
March	0	56	2	7
May	2	12	3	9
July	0	46	1	43
September	1	44	2	0
November	1	18	2	0
Mean day of year	1	20	2	20

The stations in the Assam Valley exhibit a slight acceleration similar in character but much smaller in amount and more irregular in its annual variation.

(7) Stations on the coast have their epochs earlier than the stations in the same latitude in the interior of India :—

MONTH	ACCELERATION.							
	Madras.		Rangoon		Chittagong.		Kurrachee.	
	H.	M.	H.	M.	H.	M.	H.	M.
January	−0	59	+0	33	+0	39	+0	30
March	−0	2	+0	12	−0	31	−0	1
May	+0	54	+0	11	−0	13	−0	20
July	+0	33	+0	30	+1	45	+1	48
September	−0	15	−0	18	+1	5	+0	38
November	−0	15	+1	0	+1	11	+0	35
Mean day of year	+0	17	+0	22	+0	32	+0	33

NOTE.—A negative sign prefixed to the time amount indicates that the epoch is later at the coast station than in the interior in the same latitude and a positive sign that it is earlier.

The supposition or theory that the first component of the diurnal pressure variation represents the pressure effect of the various actions and movements (or transfer of energy) due to surface absorption (or interchange of heat and energy between the ground surface and the lowest atmospheric strata), it will be seen at once, explains the more important and characteristic features of the maximum and minimum phases of that component, as shown below—

The argument on page 370 indicates that during the day hours pressure due to this action would decrease up to a minimum about sunset from a maximum shortly after sunrise and hence that these phases would vary with the season being earliest in May or June

and latest in December or January. The range of variation would evidently be greater in Northern than Southern India increasing with latitude. This is in accordance with features numbered (1) (2) and (3) in pages 371 and 372. The maximum epochs also agree closely with the epoch of *nil* difference between the ground and air temperature. The data for testing this are very limited and it is much to be regretted that observations of this element were not included in the hourly observations.

The transfer of heat from the earth's surface to the atmosphere commences when the temperature of the former in its diurnal variation begins to rise above that of the superjacent atmosphere. This according to the Jaipur observations ranges at that station (*vide* Plate IX. Figs. 7 and 8) between 9 A.M. in the cold weather (January) and 7 A.M. in the hot weather (May).

The correspondence or parallelism between the annual variation of the epoch of the maximum phase of the first component and (1) mean time of sunrise, (2) mean epoch of *nil* difference between the temperature of the ground and the superjacent atmosphere is hence marked and confirms the hypothesis.

The local variations numbered (4) (5) (6) and (7) in pages 373 and 374 stated above are of importance and are general and well marked.

The first for consideration is the slight acceleration of the maximum epoch in the diurnal variation at the coast stations (relative to stations in the interior), the amount of which is fairly constant from month to month (slightly greater in the wet than the dry season) and averages approximately twenty minutes.

It may be premised that any local peculiarity of air movement will have a corresponding local peculiarity in the pressure distribution directly and definitely related to it.

The acceleration of the epoch at the coast stations may be due either—

(1) to the local air movement exhibited most strongly in the dry season when it forms the land and sea breezes,

(2) to the local conditions of humidity and cloud which modify and accelerate the epoch of *nil* difference between the ground and air temperature.

The first appears to be of little influence compared with the second for the following reasons :—

(1) The acceleration is less in the dry season than in the wet season (*vide* data, page 281) and is hence not when the land and sea breezes are most pronounced.

(2) The acceleration is very marked at Trivandrum, Chittagong and Kurrachee in the rains. It is variable and irregular at Madras and Rangoon. This is explicable in the case of Madras where the contrast between the wet and dry seasons is slight and also very irregular.

It may hence be inferred that the acceleration at the coast stations is due to the *local conditions* of humidity an *cloud*. *In* consequence of the greater humidity (and amount of cloud) at these stations throughout the whole year than at stations in the interior the radiation from the ground surface will be much less in amount especially by night and hence the surface temperature will fall to a smaller amount and for a shorter period below the air temperature. The epoch of *nil* difference between ground and air temperature will hence be earlier and the acceleration will depend upon

the varying intensity of the determining conditions and hence be greatest in the wet season, the season of greatest humidity and cloud.

The data given in the preceding chapter (pages 281-282) are in agreement with these conclusions. The only available data for the difference between the surface and air temperature for coast stations are for Madras and, as already noted, its conditions are not similar to those of the remaining coast stations. The thermometers at Bombay for giving surface temperature have unfortunately been placed from their introduction under a thatched roof and are hence of no value for this comparison.

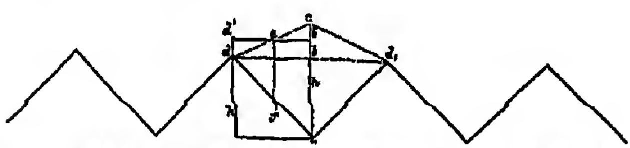
The acceleration of the epoch in Tropical relatively to Extra-Tropical India is probably due to the fact that the epoch of *nil* difference between the soil and air temperature is earlier in the former than the latter area. This is probably due to the smaller range of temperature and the greater influence of the sea.

An important feature due to local conditions is the acceleration of the epoch of the first component in mountain valleys and its retardation on mountain crests and ridges. The explanation of the peculiar features of the diurnal pressure oscillation at mountain stations is given by Dr. Hann (*vide* "Weitere Untersuchungen über die Tägliche Oscillation des Barometers.")

The following is a very brief summary of his explanation:—

"Consider the simplest case that of a broad mountain region consisting of a series of parallel ridges of triangular section with intermediate valleys of similar section, as shown in the following diagram:

Fig 1.



"Let us assume that the surfaces of equal pressure are horizontal (and the air mass in equilibrium) and that afterwards the air is heated. In consequence, the air mass in the valley will expand by amounts depending upon the length of the column of the air affected. It is evident that the air mass originally bounded by the horizontal d b d_1 will be bounded after heating (without movement) by a broken line d c d_1. Pressure will remain the same at points near the surface, but at higher points will be increased by an amount equivalent to that of the mass raised above that point. Thus at b the pressure will be increased by an amount, equal to the weight of a mass of unit section and height b c. Movement will necessarily occur, the final result of which will be that the line bounding the mass will be d^1 b^1 d^1 and pressure will be increased at d by the equivalent of mass height d d^1 and will be decreased at the bottom of the valley (a) by the equivalent of the mass b^1 c. This will be the result of the local heating and consequent movement in the valley.

"If the valley be basin-shaped the decrease of pressure at the lowest point will be for the same increase of temperature greater than in the preceding case.

"Also if the air in the valley be cooled to the same extent the pressure changes

due to the resulting air movement will be the opposite to those arising from increase of temperature. There will be an increase of pressure at the bottom of the valley and a decrease on the mountain crests. The double action will hence give rise to a pressure oscillation or variation of 24 hours period, the amplitude of which will depend upon the total change or variation of temperature, and the phases of which will be opposite in the valley and on the mountain top."

The decrease of pressure in the mountain valleys and increase on the neighbouring mountain ridges will proceed in actual practice slowly.

During the whole period of increase of temperature in its diurnal variation in these areas, the pressure changes due to this action and the reverse action by night will give rise to a pressure variation of 24 hours period, the critical epochs occurring early in the afternoon and shortly before sunrise in dry clear weather. In the rainy season in Northern India when the skies are usually heavily overcast from day to day this action will be small in amount and probably irregular in its character. There will hence be a large seasonal variation both in the amplitudes and epochs of the diurnal pressure variation at stations in the Himalayan mountain area.

It is shown in the pressure section that the epochs of the second component at mountain stations (valley and crests) are practically identical with those in the open plains, but that there are very large differences in the epochs of the first component at these stations as compared with stations in open plains. This hence suggests that the peculiarities in the diurnal oscillation at mountain stations are chiefly exhibited in the first component. This also might be inferred from the facts of the explanation given above.

The following gives the mean amplitudes of the first component and cloud amounts, month by month, at the mountain stations above 5,000 feet in elevation:—

MONTH.	MOUNTAIN PEAK.				MOUNTAIN VALLEY.			
	AGUSTIA		SIMLA.		SRINAGAR.		LEH.	
	Amplitude U_1 of pressure.	Cloud amount.*	Amplitude U_1 of pressure.	Cloud amount.†	Amplitude U_1 of pressure.	Cloud amount.†	Amplitude U_1 of pressure.	Cloud amount.*
January . . .	·00628	7·5	·00731	5·6	·00621	7·4	·01900	5·7
February . . .	·01072	5·5	·00943	5·7	·01174	6·8	·02073	6·9
March . . .	·00777	6·7	·00950	5·0	·01637	5·6	·03081	5·8
April .	·00555	7·3	·01212	4·2	·01182	4·8	·03155	6·2
May	·01570	9·3	·01705	3·9	·02170	4·0	·03040	6·0
June	·00599	9·2	·01324	5·7	·02429	3·5	·03758	4·0
July	·00587	9·4	·00943	8·8	·02953	4·0	·04581	4·6
August	·00683	9·1	·00726	8·9	·03172	3·8	·04328	4·8
September . .	·00972	8·2	·01268	5·8	·03217	3·4	·04665	3·3
October . . .	·00593	8·4	·00941	1·4	·03540	2·6	·04057	3·5
November . .	·00274	8·7	·00955	2·3	·02687	3·2	·03408	3·1
December . . .	·00361	7·9	·00960	4·0	·01806	5·9	·02752	5·5

* Means of hourly observations. † Means of 10 and 16 hours.

The data of the preceding table shew clearly that as cloud increases the amplitude diminishes and *vice versa*. If the varying elevation of the sun and hence the diurnal change of temperature be also taken into consideration it will be seen that these factors mainly, if not entirely, determine the amplitude of this oscillation.

There is also a close agreement or parallelism between the variation of the epochs and the chief seasonal features. The epochs are in all cases latest in fine dry weather when the increase of temperature during the day is large. They are earliest in cloudy gloomy weather with thickly overcast skies and rain (when the temperature variation is very small and the maximum of the day is usually accelerated).

The following table gives the epochs of the first component at the same stations:—

Month.	Mountain Peak.				Mountain Valley.			
	Agustia.		Simla.		Srinagar.		Leh.	
	H.	M.	H.	M.	H.	M.	H.	M.
January	12	18	12	20	12	11	7	18
February.	13	16	12	46	9	3	6	40
March	11	35	14	2	8	10	6	50
April	9	25	12	24	9	17	6	29
May	7	11	11	21	6	58	5	41
June	8	44	11	2	6	10	6	36
July	8	34	8	46	7	37	6	30
August	7	17	9	27	7	4	6	10
September	7	44	11	9	6	56	6	40
October	7	55	10	20	6	49	6	35
November	11	9	11	11	7	15	6	33
December	13	47	12	24	8	13	7	6

If the explanation given above be correct, the diminution of pressure at *a*, and increase, at *b* (*vide* Fig page 376) due to increase of temperature should commence about sunrise and continue up to the hottest time of the day in the valley, *i.e.*, about 2 P.M. when the reverse action and change would set in.

The data show that the maximum epochs at Agustia and Simla (stations on mountain ridges) are between noon and 2 P.M. in dry clear weather and between 7 and 10 A.M. in rainy weather with thick overcast skies. The maximum epochs in fine dry weather accord fairly with the theory or explanation. The acceleration of the epoch in the rainy season appears to be too large for the theory and indicates that there are other actions in addition to the valley action of the explanation.

The data for Leh and Srinagar show that in the Himalayan valleys the epoch of the minimum is probably much less irregular than at the mountain ridge stations. This may, however, be due to the fact that both are almost or quite beyond the influence of the great south-west monsoon humid currents. The most noteworthy features are that the minimum epochs are several hours later (6 to 7 P.M.) than the maximum temperature conditions in the valleys and that they are in the dry season, when the action is most pronounced, four to seven hours later than the maximum due to the same action on mountain crests.

These large deviations may perhaps be explained by one or other of the following :—

(1) The large general interchange or up and down air movement between the hills and plains in North-Western India. The direction and strength of the movement indicate that there is an accompanying relative increase of pressure in the lower air strata over the hills during the night hours from about sunset or shortly after, up to 8 A.M., or 9 A.M., and a similar decrease of air pressure during the day hours. This decrease during the day hours would hence tend to retard the epoch of the day minimum from about 2 P.M.,(due to the greatest valley action) probably to about 5 P.M. or 6 P.M.

(2) The slow movement of the cool air down the sides of the enclosing mountain ranges into the valleys is an action or movement additional to that of the general expansion or contraction (*vide* Dr. Hann's explanation). Dr. Hann shows that this movement will give an additional increase to that due to the general contractional effect due to decreasing temperature. This would tend to delay slightly the early morning maximum and hence the epoch of the primary or 24-hourly component of that action and of its pressure effect.

(3) The air movement producing pressure changes in the plains probably extends to the hill districts of Northern India and hence gives rise to a small oscillatory variation of pressure similar to that over the plains but of smaller amplitude.

Dr. Hann's explanation of these peculiarities (due to varying expansion and contraction in valleys) supplemented by the general alternating air movement over the Western Himalayas accounts for the following features of the first component of the diurnal pressure oscillation at these stations :—

(1) The occurrence of the maximum phase of the first component in mountain ridges about the hottest time of the day in dry clear weather.

(2) The occurrence of the maximum phase slightly (one to two hours) later in cloudy rainy weather at mountain ridge stations than at neighbouring plain stations.

(3) The occurrence of the minimum phase at valley stations in fine dry weather three or four hours later than the maximum phase at the mountain ridge stations.

(4) The large variation or acceleration of the epochs of the maximum and minimum phases at the valley stations in cloudy rainy weather.

(5) The annual or seasonal variation of the amplitude of the first component, varying inversely as the amount of cloud and hence also in part directly as the diurnal range of temperature in the valleys.

There are other (but less important) variations from the ordinary type of the diurnal pressure oscillation at a few stations in India due to certain specialized or local air movements, the chief of which are :—

(1) Land and sea breezes,

(2) Mountain and valley winds.

The effect of land and sea breezes will be similar in general character to that of the alternating mountain and plain air movement in Northern India. In other words when the movement of the lowest air stratum (in the West Coast districts, and West Ghâts more especially) is from the land to sea (during the night) it will be accompanied by a local relative increase of pressure over the hills and coast districts, and during the day when from the sea to the land it will accompany a local decrease over these districts. This is confirmed by an examination of the isobars for 10 A.M. and 4 P.M. of the months of March, May and April which show a large increase in the pressure gradients during the day, at once explained by the above considerations.

The following shows how the amplitudes of the first component are increased by this action in the dry season at Poona :—

Month.	Amplitude of first component.		
	Mean of Tropical India, Inland	Belgaum.	Poona
	"	"	"
January	·02754	·02277	·03026
February	·03177	·02216	·03241
March	·03580	·02619	·03542
April	·03585	·02634	·03239
May	·03424	·02586	·02850
June	·02292	·01189	·01672
July	·01615	·00545	·00496
August	·00061	·00762	·01016
September	·02473	·01468	·01668
October	·02617	·02022	·02705
November	·02558	·01940	·03404
December	·02335	·01692	·02865

The Epoch of the second component.—The variations of the actions, *i.e.*, of the atmospheric absorption of radiation, determining the epochs of the maximum and minimum of the second component are complex and much more difficult to estimate. Before dealing with this subject it may be well to recapitulate for easy reference the more important features of these epochs which require explanation.

(1) The annual variation of the diurnal epochs of the second component is remarkably small in India. The mean range of variation in Tropical India is 30 minutes and in Extra-Tropical India, 33 minutes. The following gives data :—

Area.	Earliest epoch (in November) A.M. and P.M.	Latest epoch (in July) A.M. and P.M.
Tropical India	9·28	9·58
Extra-Tropical India	9·44	10·17

The diurnal epochs of this component are earliest over the whole of India in November, the month of greatest serenity, and latest in the month of July, the month of greatest cloud and rain.

(2) The epochs are slightly earlier in all months in Tropical India than in Extra Tropical India. The following gives mean data:—

Month	Mean epoch of maximum phase in: Extra Tropical India (a)	Tropical India (b)	Difference. (a)—(b)
	H M	H M	M.
January	9 58	9 42	16
February	10 7	9 53	14
March	10 7	9 50	17
April	10 6	9 47	19
May	10 6	9 47	19
June	10 11	9 54	17
July	10 17	9 58	19
August	10 12	9 55	17
September	10 1	9 41	20
October	9 46	9 29	17
November	9 44	9 28	16
December	9 51	9 36	15
Year	10 2	9 45	17

The difference between the epochs in these two areas is hence remarkably constant in amount throughout the year and averages 17 minutes and is independent of seasonal changes.

(3) The most noteworthy feature of the epochs is that they are almost simultaneous over the whole area equally in the interior coast districts and in mountain valleys and on mountain peaks. This is shown clearly by the data of the following table —

Area	Mean epoch of maximum phase: On the mean day of year	January	April	July	October.
	H M.	H M	H M.	H. M	H. M
Extra-Tropical India, Inland	10 3	9 59	10 6	10 17	9 47
Ditto, Coast	9 59	9 53	10 6	10 15	9 39
Tropical India, Inland	9 47	9 43	9 49	10 0	9 30
Ditto, Coast	9 39	9 42	9 47	9 50	9 26
Mountain crest stations	10 5	10 3	10 8	10 24	9 47
Ditto, Valley stations	10 4	10 0	10 1	10 19	9 52

The data indicate (1) that the epochs relative to mean local time are very slightly (about 17 minutes) earlier in Tropical than in Extra-Tropical India and very slightly earlier in the coast districts than in the interior districts, very slightly later on mountain crests, but the differences do not exceed a few minutes and are almost within the range of probable error. That these differences are, however, real is shown by the examination of neighbouring pairs of stations (for which see page 313).

(4) There is a slight variation with season in these epochs. They are earlier in the dry season than in the rains but are remarkably uniform in each of the two seasons.

Area.	Mean of period, November to April.		Mean of period, June to October.	
	H.	M.	H.	M.
Extra-Tropical India, Inland	10	0	10	6
Ditto, Coast	9	56	10	2
Tropical India, Inland	9	45	9	49
Ditto, Coast	9	41	9	47
Mountain Crest stations	10	3	10	8
Ditto Valley stations	10	1	10	4

(5) The epochs are very slightly earlier in the Peninsula than in North-Western India or there is a slight retardation of epoch at all seasons with increase of latitude. It is somewhat irregularly shown by the stations for which data are given below:—

Month.	Epoch of maximum phase at									
	Bellary.		Nagpur.		Jubbulpore.		Jaipur.		Lahore.	
	H.	M.	H.	M.	H.	M.	H.	M.	H.	M.
January	9	52	9	48	9	53	9	52	10	21
May	10	5	9	48	9	49	9	55	10	17
July	10	4	10	10	10	3	10	14	10	35
September	9	53	9	44	9	50	9	55	10	6
November	9	39	9	31	9	35	9	40	9	57

(6) The epochs of the morning maximum of the second component of pressure in its diurnal variation agree very closely with the epochs of the maximum rate of increase of the second component of temperature in its diurnal variation.

east to west, the movement being most rapid in equatorial regions, where consequently the amplitude of the oscillation is greater than in higher latitudes under similar atmospheric astronomical and geographical conditions Owing to the rapidity of the diurnal heating of the atmosphere by the sun through its whole height, some time elapses before the higher expansive force called into play by the increase of temperature can counteract the vertical and lateral resistance it meets from the inertia and viscosity of the air Till this resistance is overcome, the barometer continues to rise, not because the mass of atmosphere overhead is increased, but because a higher temperature has increased the tension or pressure When the resistance has been overcome, an ascending current of warm air sets in the tension begins to be reduced, and the barometer falls and continues to fall till the afternoon minimum is reached. *Thus the forenoon maximum and afternoon minimum are simply a temperature effect, the amplitude of the oscillation being determined by latitude, the quantity of aqueous vapour overhead and the sun's place in the sky*"

"When the daily maximum temperature is past and the temperature has begun to fall, the air becomes more condensed in the lower strata and pressure consequently at great heights is lowered Owing to this lower pressure in the upper regions of the air, the ascending current, which rises from the longitudes where at the time the afternoon pressure is low, flows back to eastward, thus increasing the pressure over those longitudes where the temperature is now falling This atmospheric quasi tidal movement occasions the evening increase of pressure, which reaches the maximum from 9 P M to midnight, according to latitude and geographical position *The evening maximum is therefore caused by accessions to the mass of the atmosphere overhead, contributed by the ascending currents from the longitudes of the afternoon low pressure immediately to westward*"

"As midnight and the early hours of morning advance these contributions become less and less and at length cease altogether and pressure continues steadily to fall But between the time when the increase of pressure from the overflow through the upper regions of the atmosphere ceases and the time when pressure increases from the heat rays, direct or indirect, of the returning sun, or during the hours of the night when the effects of nocturnal radiation are a maximum, pressure is still further reduced from another cause Radiation towards the cold regions of space takes place, not only from the surface of the globe, but also directly from the molecules of the air and its aqueous vapour The effect of this simultaneous cooling of the atmosphere through its whole height is necessarily a diminution of its tension Since this takes place at a more rapid rate than can be compensated for by any mechanical or tidal movement of the atmosphere from the regions adjoining, owing to the inertia and viscosity of the air pressure continues to fall to the morning minimum *The morning minimum is thus due, not to the removal of any of the mass of air overhead, as happens in the case of the afternoon minimum, but to a reduction of the tension or pressure of the air, consequent upon a reduction in the temperature through radiation from aerial molecules towards the cold regions of space* In the open ocean the morning minimum is largest in the equatorial regions, and it diminishes with latitude but the rate of diminution with latitude through anti-cyclonic and other regions is generally less in amount and also more uniform than in the case of the afternoon minimum'

The following gives data for the six large groups of stations for the mean day of the year in illustration of this fact :—

Area.		Epoch of maximum increase of U_2 pressure	Epoch of maximum increase of U_2 temperature	Difference
		H M	H M	M
Extra Tropical India	Plains	10 3	10 3	0
Tropical India		9 47	10 0	—13
Extra Tropical India	Coast	9 59	9 58	+ 1
Tropical India		9 39	9 41	— 2
Mountain Crest station		10 5	9 44	+21
Mountain Valley station		10 4	10 19	—15

The correspondence, it will be seen, is almost exact, there being according to the data a slight lag of about 15 minutes in Tropical India and in the deep valleys and an advance of about twenty minutes on the mountain crests

The following monthly data for Extra-Tropical and Tropical India show that the correspondence holds throughout the whole year :—

Month	Extra Tropical India			Tropical India		
	Epoch of maximum increase of U pressure	Epoch of maximum increase of U_2 temperature.	Difference (a)	Epoch of maximum increase of U_2 pressure	Epoch of maximum increase of U_2 temperature.	Difference. (b)
	H M	H M	M	H M	H M	M
January	9 58	10 27	—29	9 42	10 13	—31
February	10 7	10 21	—14	9 53	10 14	—21
March	10 7	10 9	— 2	9 50	10 4	—14
April	10 6	10 0	+ 6	9 47	9 46	+ 1
May	10 6	10 5	+ 1	9 47	9 40	+ 7
June	10 11	9 58	+13	9 54	9 40	+14
July	10 17	10 4	+13	9 58	9 38	+20
August	10 12	9 59	+12	9 55	9 37	+18
September	10 1	9 56	+ 4	9 41	9 40	+ 1
October	9 46	9 52	— 6	9 29	9 30	— 1
November	9 44	10 1	—17	9 28	9 40	—12
December	9 51	10 17	—26	9 36	9 53	—17

It is also noticeable that the slight general variation of the retard (*a*) and (*b*) is practically the same in character for Tropical as for Extra-Tropical India and hence that it is real It may also be pointed out that the epoch of greatest increase of temperature due to U_2 follows the epoch of maximum increase of pressure U_2 from April to September

The data for the determination of the variation of the energy of the atmosphere due to mass absorption or radiation are very meagre.

During the night hours the only large and invariable process is that of radiation into space and to the earth. There is a continuous decrease of energy due to that action during this period of the day. On the other hand, during the day hours there is a continuous process of absorption of the energy of solar radiation and also of emission of atmospheric radiation into space which probably increases slightly to a maximum shortly after the hottest time of the day but depends largely for its amount on the amount of dust and cloud in the atmosphere. For a resumé of the results of investigations on this interesting subject by Maurer, Trabert and others, see Hann's Meteorology, pages 44—46.

The chief results are—

(1) Maurer, Pernter and Trabert estimate the radiation of the atmosphere to a copper plate on the ground at ·39 Kalories.

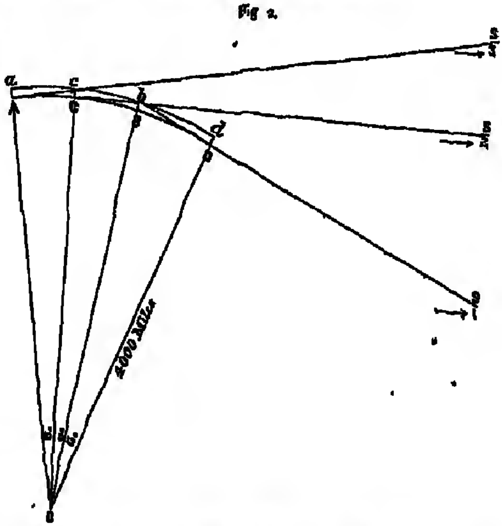
(2) Maurer thinks that the radiation by day may exceed ·50 Kalories.

The data are only valuable as showing that the terrestrial radiation is considerable to large in amount.

We have now to ascertain the approximate law of variation of the amount of the energy of solar radiation absorbed by a given mass of air during the day.

The diagram below illustrates the following discussion.—

Fig 2.

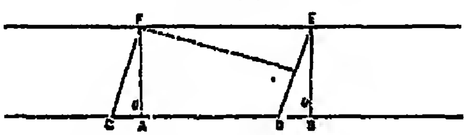


AB respresents a breadth from east to west of Northern India covering 20° of longitude. Its length north and south may be taken as unit (degree, etc.) C is the middle point, A a c b B C A represents the whole of the atmosphere to a height acted upon by radiation, which may be as much as 100 miles.

There is supposed to be no action of refraction, as this will not affect the general argument.

D is a tangent from b to the earths' surface and this line represents the direction of the sun (before sunrise) when its radiation commences to be received by the mass AB b a at the highest and most easterly point b. As the sun passes from the direction S_1 D to that of S_2 C where S_2 C is a tangent at C and to S_3 A where it is a tangent at A it will be seen that the mass of the atmosphere in the space A B b a which absorbs radiation increases continuously. If the height B b be 100 miles a simple calculation shows that the angle B O D will be approximately 13° or the total angle A O D will be about 33°. Hence during a period of about 2½ hours the absorbing mass in the space A B b a (over India, for example) will increase during a period of about 2½ hours from zero up to the total mass.

Fig. 3



The amount of energy received by the space CDEF see Fig. 3 (or practically by ADEF) in unit of time where CF is the direction of the sun making angle θ with the vertical

$$AB \sin\theta \times v \times s$$

where v and s are constants representing the velocity of light and s the energy transmitted through unit surface.

Hence the amount received per unit of time by the space (which is either absorbed or passes through to heat the earth's surface, etc.) varies as the angle of elevation of the sun and hence increases up to mid day.

On the other hand, the absorption varies directly with distance traversed according to some law which varies considerably with the atmospheric conditions and altitude of the sun.

The absorption per unit of time in the space CFED or AFED is

$CD \times f(CF) \times \frac{v}{CF}$ or will be proportional to f (cosec θ) $\times$ Sin θ.

The second factor increases with θ but the first factor decreases with θ and probably at a greater rate than the second factor increases. The amount of absorption depends upon the law of variation of absorption with angular elevation θ and is probably a complex function involving several elements, *e.g.*, amount and distribution of aqueous vapour, carbonic acid and dust in the air and their variation with distance or thickness of the absorbing layer. No observations of which I am aware furnish data from which the law may be inferred.

If, as it appears reasonable to assume, the absorption for the same mass and volume is very large when the angle θ is small and decreases very rapidly as θ increases, it follows that the absorption will decrease more or less considerably from the period when the whole mass is first affected up to the period of the greatest elevation of the sun

As already pointed out, the amount will be affected by the amount of dust and cloud in the atmosphere, hence as these tend to increase in the afternoon in both the hot weather and the rains, there will be a tendency to a slight acceleration of the epoch of the minimum absorption in these two periods.

Hence so far as can be judged from the very imperfect data the absorption of solar radiation by the atmosphere over a given area in the tropics, as for example, India has a double maximum in the course of the day. One minimum will be about or perhaps shortly before apparent noon, and there will be a prolonged minimum during the night hours when it is *nil*.

The variation of the energy due to mass absorption due to all the various co-operating actions will hence have a double maximum in the course of the 24 hours. Hence if it were expressed as a series of harmonic components the first term would have a period of 12 hours.

A calculation shows that if the whole of the solar radiation energy were utilized in heating the atmosphere the amount received in 24 hours would very approximately increase the temperature of the whole atmosphere 12° F.

The energy absorbed is, according to Langley, only about one-third of the total amount which passes into the atmosphere, and would hence, if utilized in heating the whole mass, uniformly increase its temperature by about 4° F.

This energy is probably first transformed into heat or raises the temperature of the mass. This, however, disturbs the equilibrium and gives rise to movement which in this case considering the great breadth of area almost equally affected, is primarily expansional with subsequent small horizontal movements.

There appears to be a tendency to exaggerate the amount of the horizontal movement in the upper strata due to the passage of the wave initiated by the expansion and contraction of the atmosphere accompanying the diurnal variation of temperature.

According to the best authorities (*vide* Hann's Meteorologie) the diurnal variation of temperature is almost evanescent above 5 000 feet.

This may perhaps be considered doubtful by some meteorologists, considering the character and amount of the action of absorption of solar radiation and emission by atmospheric radiation. It is, however, almost certain that the variation is very small compared with that near the earth's surface.

Assuming a diurnal variation of 30° F. in the lowest strata diminishing to 1° or 2° at 6,000 feet, it is easy to show that the acceleration due to the slope of the isobars in the middle or higher atmospheric strata would almost certainly not exceed ·0001 feet per second, and that this continued for six hours (the interval between the passage of the crest and trough of the 12-hourly component) would give a velocity of only two feet per second and a total displacement in six hours of only four miles, after which a similar return movement would occur during the next six hours. The preceding results have no pretence to accuracy, but are only given as showing the very small motions which the expansion of the atmosphere due to increased heat would give rise to, if there were no accumulation or effect due to what may be perhaps termed a resonance action—as has been established by the investigations of Margules.

Hence, as a subsidiary conclusion, it is possible, if not probable, that the commencement of movement in the direction of the gradients due to the advance of the wave

(produced by expansion and contraction of the atmosphere) may be considerably delayed, as the gradient at each transition stage (through the maximum and minimum phases of the wave) and for some time afterwards is exceedingly small and hence may not be sufficient to overcome the resistance due to viscosity.

The general character of the mass absorption of energy, more especially the regularity of its action from day to day within the tropics, is in accordance with the chief feature of the epoch of the second component (*vide* pages 380—3), *viz.*, that the epochs are almost simultaneous at all stations in India, whether in the plains or in mountain areas, or whether in the coast and in the interior.

The maximum epochs are at about 10 A.M. on the mean of the day, that is, considerably after the commencement of the absorption of the solar radiation in the air mass above India, indicating that the outflow due to the absorption or consequent heating of the air occurs from four to five hours after the commencement of the process of absorption. This retardation in the present case of the decrease of pressure which usually accompanies increase of temperature of any large mass of the atmosphere is probably due to the actions or causes stated above (page 386.).

It appears, however, to be more in accordance with the investigation of Margules to suppose that the secondary wave which passes round the earth in any day is not to be explained as a result of the actions and variations of energy of that day, but that it is an accumulation of effect due to a resonance action, and that there may be a considerable retard in the epochs of this wave over the epochs of the daily variation of energy of the atmosphere.

Also, if the assumption or hypothesis of the double maximum of absorption be correct, it is clear that the epoch of the first maximum of the mass absorption will be accelerated and the second retarded as the season advances from January to June and that the opposite variations will obtain during the remaining half of the year. The midday minimum will, however, be unaltered in its epoch with the seasonal changes of the sun's elevation, and will hence probably be the main factor in determining the epochs of the Besselian resolution which will hence be almost unchanged throughout the year. The following data for Extra-Tropical and Tropical India, Inland, show that this is the case:—

Area.	Mean epoch of the maximum phase of the second component in											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.
Extra-Tropical India, Inland	9 59	10 7	10 7	10 6	10 5	10 11	10 17	10 12	10 8	9 47	9 46	9 [illegible]
Tropical India, Inland	9 43	9 55	9 52	9 49	9 48	9 36	10 0	9 56	9 42	9 39	9 39	9 39

The epochs in Tropical India are slightly earlier than in Extra-Tropical India (by amounts averaging 16 minutes.) This is, as in the case of the first component probably due to the contrast between the air movement over the comparatively narrow belt of the Peninsula, as compared with that over Northern India.

The epochs at the coast stations are slightly earlier than at the inland stations. This is also apparently a differential actioo due to the greater humidity and cloud at the coast stations, more especially in the afternoon hours, one result of which is to accelerate the epochs of maximum of both first and second components of the temperature variation.

There is, on the other hand, a very slight retardation at mountain stations. Professor Hann has given an explanation in accordance with his general theory of the local actions and air movements in mountain valleys and finds in it a confirmation of that theory.

In the preceding remarks an attempt has been made to connect the epochs of the first and second components with the large actions producing them.

Comparison of epoch of evening maximum of the pressure oscillation and of the diurnal minimum of cloud.—In the following pages (388—391) certaio comparisons are giveo to test statements that have been made with respect to the correspondence of certaio features of the diurnal oscillation and the variations of other elements of observation.

Blanford has stated that the epoch of evening maximum of the semi-diurnal pressure oscillatioo agrees with the diurnal minimum of cloud. The following table gives data for twelve representative stations under discussion :—

Station.	Epoch of evening maximum of pressure (U_2)					Epoch of diurnal minimum of cloud.				
	Mean of year.	January.	April.	July.	October.	Mean of year.	January.	April.	July.	October.
	P.M.	P.M.	P.M.	P.M.	P.M.	P.M.	P.M.	A.M.	P.M.	P.M.
Lahore . . .	10-23	10-31	10-22	10-35	9-56	10-50	10-30	1-50	11-10	11-0
								P.M.		
Kurrachee . . .	9-49	9-41	9-57	10-9	9-28	8-30	10-51	10-50	8-43	8-30
Lucknow . . .	10-6	10-4	10-9	10-18	9-51	9-0	10-0	10-0	8-10	10-0
Allahabad . . .	9-59	9-54	10-1	10-16	9-44	9-0	10-50	9-30	8-41	7-0
Hazaribagh . .	10-13	10-7	10-20	10-23	10-1	9-10	11-16	8-8	11-11	8-26
Dhubri . . .	10-7	10-3	10-23	10-19	9-47	8-30	9-30	6-56	8-44	9-37
Goalpara . . .	10-4	9-56	10-4	10-13	9-58	8-11	6-59	8-39	8-11	7-55
Sibsagar . . .	9-57	9-54	10-5	10-8	9-53	8-8	10-55	9-47	5-52	7-6
Chittagong . .	10-4	10-1	10-9	10-13	9-45	10-0	10-50	2-23	10-20	10-0
Rangoon . . .	9-54	9-45	10-1	10-10	9-43	10-10	9-30	11-30	11-18	10-0
										A.M.
Pachmarhi . .	9-59	9-54	10-3	10-16	9-42	11-0	11-10	10-54	11-0	0-10
Aden	9-40	9-34	9-59	9-56	9-20	4-0	4-30	9-53	1-0	0-6

The comparisoo betweeo the two sets of data shows that the correspondence is far from exact, and that the differences between the two series of epochs vary considerably and apparently irregularly.

It is hence probable that the correspondence is not due to any direct relation but perhaps to both being results of the same large atmospheric movements.

Comparison of epoch of the morning maximum of the diurnal pressure oscillation and of the greatest rate of increase of temperature in its diurnal variation.—It has been stated that the epoch

of the morning maximum of the diurnal oscillation of pressure corresponds closely with the period of greatest rate of increase of temperature. The following gives data in illustration :—

STATION	EPOCH OF MORNING MAXIMUM OF PRESSURE (COMPLETE VARIATION)					EPOCH OF GREATEST RATE OF INCREASE OF TEMPERATURE (COMPLETE VARIATION).					EPOCH OF GREATEST INCREASE OF THE FIRST AND SECOND COMPONENTS OF THE DIURNAL VARIATION OF TEMPERATURE ON THE MEAN DAY OF YEAR.	
	Mean of year.	January.	April.	July.	October.	Mean of year.	January.	April.	July	October	24 hourly component.	12 hourly component.
	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M	A.M.	A.M.	A.M	A.M.	A.M.
Kurrachee	9·28	9·37	9·32	9·28	9·12	8·51	9·15	8·34	8·8	8·48	8·20	9·42
Lahore	10·4	10·8	10·9	9·55	9·46	8·48	9·25	8·34	8·53	8·33	8·44	10·15
Jaipur	9·42	9·50	9·42	9·37	9·30	8·29	8·50	8·9	8·37	8·11	8·30	10·6
Deesa	9·27	9·43	9·23	9·28	9·16	8·34	8·46	8·24	9·47	8·14	9·2	9·48
Allahabad	9·38	9·47	9·33	9·44	9·29	8·45	9·17	8·20	8·31	8·37	8·32	10·6
Patna	9·36	9·37	9·28	9·49	9·26	8·40	8·57	8·26	8·8	8·12	8·56	9·59
Dhubri	9·37	9·42	9·38	9·27	9·25	9·23	9·58	8·48	8·44	9·8	9·7	10·32
Sibsagar	9·32	9·37	9·33	9·38	9·25	9·8	9·46	8·35	9·26	8·47	9·15	10·42
Cuttack	9·24	9·33	9·13	9·29	9·15	8·54	9·11	9·16	8·28	8·32	8·28	10·13
Rangoon	9·28	9·28	9·21	9·30	9·21	8·58	9·3	9·2	8·51	8·30	8·21	10·0
Jubbulpore	9·30	9·41	9·34	9·47	9·14	8·46	9·14	8·23	8·39	8·34	8·58	10·1
Nagpur	9·30	9·40	9·22	9·38	9·21	8·28	9·8	7·55	8·46	8·13	8·50	9·57
Poona .	9·16	9·19	9·4	9·48	9·5	8·35	8·54	8·17	8·36	8·18	8·39	9·44
Belgaum	9·28	9·27	9·30	9·27	9·20	8·24	8·31	8·29	8·25	8·11	8·1	9·46
Bellary	9·30	9·38	9·33	9·30	9·20	8·43	8·52	8·41	9·34	8·26	9·0	10·15
Trichinopoly . . .	9·22	9·34	9·26	9·10	9·18	8·42	8·36	8·37	9·6	8·35	8·45	10·19
Trivandrum . . .	9·16	9·17	9·23	9·30	9·5	8·11	8·26	8·5	8·5	8·5	8·0	9·14
Mean of all stations .	9·31	9·27	9·29	9·34	9·20	8·43	9·4	8·30	8·45	8·28	8·40	10·2

The data show that the epoch of the greatest rate of increase of temperature almost invariably precedes the morning maximum of pressure by a short interval. The former on the mean of the stations for which data are given is 8·43 A.M., and the latter 9·31 A.M. for the mean of the year, thus, showing a difference of almost exactly three quarters of an hour. The difference varies to some extent during the year and ranges between 33 minutes in January and 59 minutes in April. The differences are hence approximately constant throughout the year, and are such as to indicate that the epoch of the morning maximum of the total diurnal pressure oscillation is closely related to, and probably in part at least determined by, the greatest rate of increase of temperature in its diurnal variation.

The following table gives the epochs of the maximum rate of increase of U_1 and U' of temperature for the mean day of year and for the months of January, April and July,

representative of the cold and hot weather seasons and the rainy season for ten representative stations :—

Station.	Mean epoch of maximum rate of increase of U_1 on the mean day of year.	Mean epoch of maximum rate of increase of U_2 on the mean day of year.	Mean epoch of maximum rate of increase of first and second components of temperature in Cold weather (January).		Hot weather (April).		Rains (July).	
			U_1	U_2	U_1	U_2	U_1	U_2
	A.M.	A.M. & P.M.	A.M.	A.M. & P.M.	A.M.	A.M. & P.M.	A.M.	A.M. & P.M.
Bellary . . .	9-0	10-15	9-12	10-28	9-16	10-21	8-24	10-15
Belgaum . . .	8-1	9-46	8-42	10-9	7-46	9-44	6-58	9-14
Nagpur . . .	8-50	9-57	9-11	10-25	8-41	9-33	8-23	9-38
Jubbulpore . . .	8-58	10-1	9-10	10-26	9-0	9-29	8-46	10-30
Calcutta . .	8-27	10-22	8-56	10-50	8-25	10-31	8-0	9-23
Patna . . .	8-56	9-59	9-9	10-6	9-3	9-55	8-45	9-59
Allahabad . . .	8-32	10 6	8-49	10-28	8-36	9-47	8-34	10-7
Jaipur . . .	8-30	10-6	8-40	10-24	8-32	9-52	8-48	10-8
Deesa . . .	9-2	9-48	9-5	9-44	9-5	9-46	9-35	10-37
Lahore . .	8-41	10-15	8-48	10-42	8-44	10-0	8-57	10-8
Mean of all stations .	8-42	10-4	8-59	10-22	8 43	9-54	8-31	10-0

The following table gives the epochs of the maximum values of the first and second components of pressure for the same stations for comparison with the preceding data :—

Station.	Epoch of maximum values of first and second components of pressure in Year.		Cold weather (January).		Hot weather (April).		Rains (July).	
	U_1 A.M.	U_2 A.M. & P.M.	U_1 A.M.	U_2 A.M. & P.M.	U_1 A.M.	U_2 A.M. & P.M.	U_1 A.M.	U_2 A.M. & P.M.
	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.
Bellary . . .	6-30	9-55	6-56	9-52	7-11	10-4	5-12	10-4
Belgaum . . .	6-27	9-37	6-40	9-31	6-42	9-37	6-30	9-52
Nagpur . . .	7-4	9-51	7-38	9-48	7-22	9-59	7 4	10-10
Jubbulpore . . .	7-12	9-50	7-38	9-53	7-32	9-55	7-2	10-3
Calcutta . . .	6-56	10-4	7-37	9-57	7-21	10-11	6-41	10-24
Patna	7-2	10-2	7-13	9-56	7-17	10-7	6-22	10-28
Allahabad . . .	7-38	9-59	8-13	9-54	8-6	10-1	6-42	10-16
Jaipur . . .	7-55	9-57	7-55	9-52	8-14	10-2	7-32	10-14
Deesa . . .	7-20	9-46	7-53	9-40	7-52	9 42	7-39	10-7
Lahore . . .	8-32	10-23	8-20	10-21	8-12	10-22	8-7	10-35
Mean of all stations .	7-16	9-56	7-36	9 53	7-36	9-59	6-47	10-12

The comparison of the data in the preceding table leads to the following inferences :—

(1) The mean epoch of the greatest increase of the first component of temperature averages about 8-45 A.M. over the whole of India and occurs (leaving out apparent local irregularities) at practically the same instant over the whole of India.

(2) It is practically unchanged in the dry season, but is from 15 to 56 minutes earlier in the rainy than the dry season over the Peninsula, Central and North-Eastern India. It varies very little in Upper India, the driest area in the rains.

(3) The mean epoch of the greatest increase of U_1 of temperature on the mean day of the year is 10 A.M. approximately and varies little over the whole of the year, and is almost simultaneous with the morning maximum epoch of the second component of pressure.

(4) The epoch of the second component is slightly earlier in the hot weather and the rains than in the cold weather, except in North-Western India, where it is slightly retarded during the rains. The relations between the epochs of the first component of the diurnal temperature variation and the morning maximum of pressure are similar to those which have been shown to obtain between the epoch of the total temperature variation and the morning maximum of the pressure oscillation. This is of course due to the fact that the first component is the predominant factor or term in the diurnal variation of temperature.

Comparison of the diurnal oscillation of air pressure and the diurnal variation of temperature and other elements of observation.—In the following paragraphs is discussed the question of the relations that obtain between the diurnal variation of air pressure and the diurnal variation of aqueous vapour pressure, cloud, air movement and temperature.

A. Aqueous vapour pressure.—The more noteworthy features of the diurnal variation of this element have been given in Chapter V, pages 114 to 159.

Curves representing the annual march of this element for fifteen stations are given in Plate XXIII, and curves representing the diurnal variation for four or five groups of stations (arranged according to types) for each of the four seasons into which the year is divided, will be found in Plate XXIV.

Corresponding data for each of the four seasons for each of the 28 stations at which hourly observations were recorded will be found in Plates XXV to XXX.

Curves giving the diurnal pressure at Srinagar deduced from a short series of hourly observations during the year will be found in Plate XXXI.

These curves, more especially those of Plates XXIII, XXIV and XXXI appear to deserve careful examination in connection with the general investigation of the phenomena of the diurnal changes of meteorological conditions in India.

The curves in Plate XXIII, illustrating the annual variation of aqueous vapour pressure in different parts of India, indicate the close and intimate relation between that element and the large seasonal changes and the connected air movements. These curves, as might be expected, are similar to the corresponding curves for the annual variation of temperature

and range of temperature (*vide* Plates X, XI, XII and XIII) They are simpler and more regular than the temperature curves but, like the latter, indicate a large annual variation with a single minimum and maximum for all stations except those in Southern India where the rainfall due to the south-west monsoon currents has a double periodicity.

The minimum value of the aqueous vapour pressure is in January or February, or slightly later than the minimum epoch of the annual variation of temperature which is at most stations in December or January. The maximum epoch of aqueous vapour pressure, as a rule, coincides with the month of greatest influence and intensity of the south-west monsoon conditions—and hence in June or July but depending to a very slight extent upon the position of the station. This epoch is hence from one to two months later than the maximum value of the annual variation of temperature.

A comparison with the corresponding curves for pressure shows that the pressure curves are roughly the inverse of the aqueous vapour pressure. This is due, of course, to the fact that both series of changes accompany and are in part determined by the great seasonal changes in the general air movement over India.

The discussion in Chap. V has shown that the curves representing the diurnal variation of aqueous vapour pressure at the stations in India, may be grouped in two main types. The first type has only one maximum and minimum in the 24 hours and the second type two maxima and minima values during the day

To the first type belong the variations at Srinagar and the Assam Valley. The curves for Srinagar given in Plate XXXI show this type of variation most fully. These curves have their minima at about 6 A.M. (the coolest period of the day) and their maxima values at 3 P.M. to 4 P.M. or very shortly after the hottest time of the day.

They are almost identical in form with the curves representing the diurnal variation of temperature at Srinagar and represent the effect of evaporation with its allied processes and actions in modifying aqueous vapour pressure in the lowest air stratum during the course of the day (as pointed out in page 153). The conditions of the Kashmir Valley are peculiarly favourable for large evaporation effects, and for the absence of convective action. The Srinagar curves may hence be accepted as giving the form of the curve of variation due to evaporation only, the only important variation from one station to another and from one season to another being in the amplitude of the diurnal variation.

The additional general action which converts this variation of 24 hours period into a double variation is that of the convective movements set up during the day hours by the rapid increase and variation of temperature in the lowest air stratum. This convective action is restricted to the day hours from about 8 A.M. to 5 P.M. and gives rise to a continuous decrease of aqueous vapour pressure during the period of increase of convective movement from 8 A.M. to about 2 or 3 P.M. and an increase thence to 5 or 6 P.M. when the movement and action ceases.

A discussion of the variation of the aqueous vapour pressure due to this course will be found in Chap. V, and it is not necessary to add anything further on this point.

This second action and effect it will be seen occurs directly in the lowest stratum and hence, if it is related to the diurnal variation of pressure, the relation should be sought in the first rather than the second component. The same is also the case for the results of evaporation.

A comparison of the curves in Plates LXV to LXX giving the annual variation of

The following is a very brief summary of the above:—

(*1st*) The 10 A.M. or morning maximum is a direct temperature effect—temperature at this stage gives rise to increased pressure due to the inertia of the air.

(*2nd*) The 4 P.M. or afternoon minimum or the decrease of pressure between 10 A.M. and 4 P.M. is also a direct temperature effect—the temperature changes during the period chiefly giving rise to ascensional and convective movements.

(*3rd*) The 10 P.M. or evening maximum or the increase of pressure between 4 P.M. and 10 P.M. is due in part to a backflow from the low pressure wave in front and also to compression by cooling and descending air masses.

(*4th*) The 4 A.M. or morning minimum and the preceding decrease of pressure are mainly due to actual diminution of air pressure, and not of amount or mass, consequent upon reduction of temperature in the higher strata produced by radiation towards the colder regions of space.

(2) HANN.—On the whole the most important contributions to the subject are Dr. Hann's "Untersuchen über die Tägliche Oscillation des Barometers." Dr. Hann considers that the barometric diurnal oscillation is mainly due to the absorption of the solar radiation in the higher atmospheric strata. His investigations were hence partly undertaken to test whether there is an annual variation in the diurnal oscillation corresponding to the periodicity of solar activity determined by its varying distance from the earth during the year.

Dr. Hann points out that the resolution of the diurnal oscillation into harmonic components by the Besselian formula is essential to a true comprehension of the facts and that the first two components obtained by this method are independent elements, components or constituents due to the action of independent causes. The first component (the period of which is 24 hours) is very variable, whereas the second component is remarkably regular amidst the changes of season and weather and also of latitude.

Dr. Hann applies the Besselian analysis to the observations of a very large number of stations and the comparison of the results leads to the following conclusions respecting the amplitudes and phases of the first, second and third components respectively:—

(*A*) Amplitude of first component (U_1).

(1) U_1 shews large differences at neighbouring places in the same latitude and is very variable and irregular.

(2) U_1 is large for stations in mountain valleys, from two to three times as large as in open places in similar latitudes, but the diurnal oscillation in valleys is in other respects normal.

(3) U_1 is also large for coast stations in low latitudes.

(4) In low latitudes (0° to 35°) U_1 has its maximum value usually in May and minimum in July or August.

(5) U_1 is small for stations on mountain peaks or the crests of mountain ranges.

(6) U_1 shews large irregularities from place to place, and it is difficult to formulate a simple law for its variation with latitude.

(7) In equatorial regions, and hence over the greater part of India, U_1 has its absolute maximum in April or May and its minimum in July. There is also

the actual vapour pressure and of the amplitudes of the first and second components of the pressure oscillation for fifteen stations leads to the following inferences:—

(1) The annual variation of the aqueous vapour pressure at the great majority of stations differs largely from that of the amplitude of the first component, and very largely from that of the second component. There is no clearly defined direct or inverse relation between these elements.

(2) The annual variation of the aqueous vapour pressure is at the great majority of stations a regular curve having one maximum and minimum, and approximately similar to the annual variation of temperature but inverse to the curve representing the annual variation of the amplitudes of the first and second components of the Besselian resolution of the diurnal variation of temperature. This inverse correspondence is due chiefly to the fact that the amplitude of the diurnal variation of temperature varies inversely with respect to the amount of aqueous vapour present in the air in the larger seasonal changes in India.

(3) The annual variation of the first and second components of the Besselian resolution of the diurnal variation of aqueous vapour pressure differ very widely from station to station and present large irregularities, in which respect they differ greatly from the annual variation of pressure, temperature and air movement. This is of course an example of the very great variability of this element of observation, frequently due to very slight differences of local conditions, etc.

The variations are related in part to the hygrometric quality of the prevailing winds and to the occasional large variations of this element during the day and hence are very large at stations such as Kurrachee, Calcutta, Poona, Belgaum, etc., where land and sea breezes at certain times of the year give rise to large and sudden changes of the aqueous vapour pressure.

The combination of the 24-hour variation due to evaporation and the day variation due to convective movement gives rise, as previously stated, to the diurnal variation with two maxima and minima which obtains at most stations. The epochs and amplitudes of this double oscillation depend upon the relative intensity of the two actions. There is usually as might be expected little variation in the epochs The minimum values are usually in the morning about 5 or 6 A.M. and shortly after the hottest time of the day, *i.e.*, about 2 or 3 P.M. The maxima vary more largely, depending far more upon the relative intensity of the two actions, but are usually at about 9 A.M. and 8 P.M. These epochs are not similarly related throughout to the epochs of the diurnal oscillation of pressure.

The comparison hence leads to the conclusion that there is no direct relation between the diurnal variation of air pressure and of aqueous vapour pressure. The variation of the latter usually represents a local effect, whereas that of air pressure in virtue of the very great rapidity with which pressure changes are transmitted through the atmosphere and readjustment effected represents the mean integrated effect of action over a large area.

There are undoubtedly relations between the two but they are indirect and are due to the changes of air movement set up by changes in the amount of aqueous vapour present in the air. Cleveland Abbe's discussion on "buoyancy" in his preparatory studies is of special value in studying this aspect of the question

B. Cloud.—The data and discussion of this element of observation are given in Chapter VI, pages 160 to 201.

Curves representing the annual variations of this element for 29 stations will be found in Plates XXXVIII and XXXIX. Also curves representing the diurnal variations of four or five groups of stations (arranged according to types of cloud variation) for each of the seasons into which the year is divided are given in Plate XL. Curves representing the mean actual variations in each of the four seasons for 27 stations at which hourly observations were recorded will be found in Plates XLI to XLVI.

The curves in Plates XXXVIII and XXXIX representing the annual variation of the cloud have been already discussed. It is sufficient to repeat that they show the direct connection between the amount of cloud and the larger seasonal features of the year. Thus in North-Western India the cloud curves exhibit two maxima values, the first in the cold weather corresponding to the period of the cold weather rains and the second in the height of the monsoon rains (July or August). For stations in North-Eastern and Central India and the West Coast and Deccan where there is only one rainy season and one maximum of rainfall, the cloud curves have only one maximum and minimum. At the Southern Indian stations the cloud curves are less regular due to the fact that the precipitation in the rainy season and the accompanying actions have two feeble maxima, one at the commencement and the other near the end of the monsoon

The annual curves for aqueous vapour pressure and cloud resemble each other in their main features, indicating that both are dependent upon the same general seasonal changes.

The curves in Plate XL representing the diurnal variation of cloud in the four seasons of the year arranged according to types deserve careful study in connection with the diurnal variation of pressure.

The diurnal variation of cloud differs largely from season to season and also from place to place in which respects it differs fundamentally from the diurnal variation of pressure. There is also no similarity between the complete diurnal variation of the two elements. The diurnal variation of cloud has in some cases only one maxima and minima, in others two, in others three and even more.

There is hence no general parallelism underlying the diurnal variation of cloud and of pressure in any season or at any considerable group of stations, and it may therefore be inferred that there is no general direct relation between the diurnal variation of air pressure and of cloud.

There is one feature in the diurnal variation of cloud which appears to deserve careful consideration in connection with the diurnal variation of pressure. This is a considerable and usually rapid increase of cloud amount in the early morning, shortly before sunrise and in most cases from 4 A.M. to 6 A.M. or 7 A.M. The period of this, it may be noted, varies slightly with the season and is latest in the cold weather when days are shortest and earliest when days are longest.

Considering that it is more difficult to estimate cloud amount by night than by day and that the tendency amongst our Indian observers is to under-estimate it at night, it is certain that this feature is not due to any defect of observation but is most probably under-estimated. An examination of the curves in Plate XL will at once show what a marked feature of the cloud variation this comparatively rapid rise from about 4 A.M. to 6 A.M. is.

The cloud formation at this period of the day occurs at all seasons and over the whole of India and is hence a general and not a local action. It occurs during the night hours in the absence of expansive and convective movements and when the only general movement is slow descent and contraction due to cooling. The only possible explanation is that it is due to cooling of a nearly saturated air stratum by radiation. This explanation accounts for the sudden increase at a critical period which averages 4 A.M. The cooling of the air continues until about sunrise. The process of condensation and cloud formation implies the release from what is usually termed a latent stage of a large amount of energy to the mass of air containing the condensing aqueous vapour. It apparently does not set up in the slowly contracting air mass the upward movement necessary to the readjustment of pressure and hence there is very probably a local and temporary increase of pressure which is transmitted. If this explanation be correct, it suggests that the increase of pressure in the diurnal oscillation from about 4 A.M. to sunrise at the coolest period of the 24 hours may be, in part, due to the considerable condensation of aqueous vapour which occurs in all seasons in the middle or higher atmospheric strata in India during this period of the day.

The large increase of cloud in the warmest part of the day is due to the large convective movements which occur at that time and increase for sometime the intensity of that movement and hence of the accompanying horizontal movements and pressure changes. It is probable that this to some extent accounts for the variability in the amplitude of the first component in different parts of the interior of India.

The correspondence between the cloud and the aqueous vapour pressure curves which is at once seen by comparing curves for the same stations in Plates XXIII and XXXIX is interesting as the former gives a feature of the middle atmosphere and the latter of the lower atmosphere, thus indicating that the seasonal conditions determining these variations affect similarly by far the greater depth or part of the atmosphere over India.

The comparison of the U_1 curves for pressure with the cloud curves of the seven representative stations and the aqueous vapour curves shows the dependence and variation of each with the broad distinction between the wet and dry seasons, but there are large differences, local and seasonal, which indicate that the variation of U_1 cannot be related directly to either aqueous vapour or cloud. That is, there are variations (secondary maxima and minima, etc.) which exist in one that have no counterpart in the other. Hence it is not possible to look to these elements for the direct explanation of the chief features of the diurnal oscillation of pressure.

C. Temperature.—In Plates LXV to LXX are plotted the annual variations of the amplitudes of the first and second components of the Besselian resolution of the diurnal variations of pressure and temperature and the annual variation of temperature and of the diurnal range of temperature for 15 stations.

The following gives the chief results of the examination of the curves in these six plates :—

(1) The annual variation of U_1 for pressure is large and well marked, the chief features being a pronounced maximum in the dry season, and minimum in the rainy season. At several stations including Bombay, Calcutta and Nagpur the curves have only one maximum and minimum. The curves

differ very considerably in form as well as in amplitude at neighbouring stations due in part to local peculiarities of conditions. They also indicate that at most stations there is a second maximum and minimum at the end of the wet season, most pronounced at Rangoon and Chittagong. The annual variation of U_1 for temperature is a simple curve for all except the South Indian stations and Aden, having its maximum in February and minimum in the rains (July or August) Curves representing the annual variation of the first component of temperature and pressure differ so largely in form at many stations (as for example Aden, Madras, Bellary, Rangoon, Bombay, Lahore, Allahabad, and Jaipur) as to indicate there is no direct relation between the two except in the one fact that *each exhibits an annual variation of considerable amplitude due to the same* general seasonal variation of conditions. The absolute minimum in the temperature curve is generally later than that of the minimum of the corresponding pressure curve, whereas the maximum of the temperature curves is from one to two months earlier. The periods, critical epochs and forms of the curves of U_1 for pressure and temperature do not present the parallelism that is required to establish that the first component of the pressure variation is directly related to the variation of the corresponding element of temperature and is expressible as a simple function of the latter.

(2) The correspondence between the U_1 curves for pressure and U_2 curves for temperature is even less than with U_1 for temperature.

The annual variation of U_2 for temperature is small in amplitude for all stations as compared with that of U_1 but follows approximately the same law of annual variation. The representative curves vary largely from station to station. They have at most stations only one maximum and minimum, the former in the cold weather (*December, January or February*), and the latter in the rains (generally July). The want of parallelism between the two sets of curves is most clearly seen from an inspection of the curves for Jaipur Allahabad, Calcutta, Lahore, Rangoon, Bombay, Jubbulpore, Nagpur, Bellary and Madras. Hence the annual variations of the amplitude of the first component of pressure and the second component of temperature differ so widely in form and in their critical epochs as to indicate there is no direct relation between these two elements.

(3) There is, on the other hand, some resemblance between the U_2 curves for pressure and the U_1 and U_2 curves for temperature. All have a maximum, (absolute) in the dry season (usually February or March) and a *minimum* (absolute) in the wet season, usually in July. In some cases the resemblance is greater between the curves for the annual variation of U_2 of pressure and those for U_1 of temperature and in others between the curves for U_2 of pressure and U_2 of temperature The resemblance is not however strong enough to suggest that one is the cause of and directly related to the other. The utmost that can be said is that probably the annual variation of all three is due to the same general causes, *viz*, general meteorological actions that are at a maximum in the dry season and at a minimum in the height of the rains.

(4) The comparison of the U_2 curves for pressure and U_1 for temperature (Plates LXV, LXVI and LXVII) discloses an almost complete absence of parallelism except in the one feature that both sets of curves have a maximum and minimum at the same season of the year. A comparison of the curves for Bombay and Aden on the one hand and for Allahabad and Jubbulpore on the other shows that a large range of variation for one element may accompany a small range of variation in the other and *vice versâ*. Also in some cases the critical epochs of the absolute maximum and minimum of the U_1 temperature curve precede those of the U_2 of pressure (as at Chittagong and Rangoon) and in other cases (*e g*, Lahore, Jaipur and Allahabad) they follow and in a few cases (*e g*, Jubbulpore, Poona and Bellary) they are simultaneous. Also in some cases, as for example Aden, Madras, Lahore and Chittagong, they differ so largely in form as to show that there is no direct relation between the elements which they represent

(5) Similarly, the comparison of the curves representing the annual variation of the second component of temperature with those representing the second component of pressure shows, as in the preceding comparison (4), that they differ considerably and irregularly in their critical epochs, largely in the form of the curves or the law of the annual variation of the two elements and more especially in the relation of their amplitudes, large amplitude in one accompanying relatively small amplitude in the other, and *vice versâ*

(6) Similar conclusions follow from a comparison of the curves representing the annual variation of the diurnal range of temperature and the curves representing the annual variations of the first and second components of pressure The same conclusion at once follows from the consideration that the curves for the former are almost identical with the U_1 curves for temperature, the diurnal variations representing the combination of the four components (U_1, U_2, U_3 and U_4) of which U_1 is by far the most important

(7) *There is hence no direct relation between the amplitudes of the first and second components of pressure and temperature of such a nature that one can be expressed as a function of the other*

It may also be pointed out that the first and second components U_1 and U_2 of temperature are almost certainly not independent of each other in which respect they differ from the corresponding pressure components. The following gives reasons —

In the first place U_1 and U_2 vary similarly in amplitude and epoch in such a manner as to show they are component parts of a general variation. This is at once seen by a comparison of the curves giving the annual variation of these two elements in Plates LXV, LXVI and LXVII. In the second place, the 24-hourly actions giving rise to the diurnal variation of temperature are not subject to the simple harmonic law, and hence the resultant temperature variation could not possibly be simply harmonic Hence the second component or twelve-hourly element is a necessary element of the resolution of the diurnal variation and is not an independent element due to different actions from those giving rise to the variation represented by the first component There are undoubtedly variations of other elements of observation affecting temperature which have an approxi-

main twelve-hourly period, more especially the variations in the amount of aqueous vapour present in the atmosphere, cloud amount and distribution, etc.

It is however certain that these exercise a very slight diurnal effect on the temperature of the lowest stratum, a part practically negligible compared with the resolved part of the irregular twenty-four hourly action.

It is also doubtful whether the twelve-hourly component increases or decreases in relative importance with elevation. It undoubtedly decreases with the amount of aqueous vapour present in the air and *vice versâ*. The only data available are for mountain stations, and they are not satisfactory as they (more especially the valleys) do not give the variations, etc., in the open. It is assumed by some meteorologists that the form of the curve representing the diurnal variation of temperature is similar throughout a great height of the atmosphere, but this, although on the whole probable, has not been established by direct observation.

The chief results of super-imposing the twelve-hourly component on the twenty-four-hourly component of temperature are at once seen by reference to the curves of Plate LXXIII. In that plate three curves are given for each of the stations of Allahabad and Jaipur for the months of December, May and July, typical of cold weather, hot weather and rainy season conditions. Each set of curves gives the diurnal variation of the first and second components and of the resultant of their combination.

It should be noticed as a striking feature of the U_2 curves that the amplitude is greatest in the cold weather when the diurnal range is greatest and decreases until the middle of the rains

The chief inferences derived from an examination of those curves are—

(1) The morning minimum of the resultant curve is in all cases considerably later than that of the first component (or the U_1 curve) by amounts averaging about two hours. The epoch of the minimum of the combined curve is from about 5 A.M. to 5-30 A.M. or very shortly before sunrise. The resulting temperature due to the combination is greater during the night hours from about 10 P.M. to 4 A.M. than in the U_1 curve.

(2) The day maximum of the combined curve is slightly earlier than in the U_1 curve, the acceleration averaging about one hour. The resulting temperature due to the combination of U_1 and U_2 is greater than that due to U_1 from about 10 A.M. to 4 P.M., the maximum difference decreasing from about 4° in December to 1° in July.

Hence the chief effect of super-imposing U_2 on U_1 in temperature is to retard the morning minimum, accelerate the midday maximum, exaggerate or increase the midday temperature and increase the night temperature. The combination of the two gives very closely the actual diurnal variation.

The want of similarity pointed out above between the first and second components of pressure and temperature however in no way invalidates the arguments referred to in pages 325 to 327. Thomson (Lord Kelvin) threw out the suggestion years ago that the period of the free oscillatory movement of the atmosphere might be about 12 hours and if so, that in accordance with dynamical principles a comparatively

small twelve-hourly component of temperature (whatever its origin or character) might give rise to a large corresponding oscillation of pressure of that period. Margules has established that under certain conditions the free period of oscillation of the mass of the atmosphere is approximately 12 hours, thus confirming Lord Kelvin's supposition and strengthening the probabilities of the conclusion based on it.

There is hence a considerable probability that the twelve-hourly component of pressure may be due in part at least to a resonance action, and that this may contribute to the largeness of its amplitude, more especially when compared with that of the first component.

This however does not invalidate the conclusions based on the comparisons given in the preceding pages. It may however be pointed out that this argument is based on an important principle, *viz.*, that the diurnal oscillation on any given day is not to be explained by the actions or conditions of that day only. It is a regular movement fully established and maintained by a more or less regular periodic addition and subtraction of energy in the atmosphere and the smaller local and irregular variations from day to day are almost obliterated by the general actions.

As the conclusion given in italics in page 397 is of great importance for the discussion, it appears to be desirable to give numerical data in further support and confirmation of the statement.

The following gives data (1) for Extra-Tropical India, Inland, and (2) for Tropical India, Inland, of the amplitudes of the first or second component of pressure and either the first or second component of temperature :—

Comparison of U_1 of pressure with U_1 and U_2 of temperature.

Month.	Extra-Tropical India, Inland			Ratio of a to b.	Ratio of a to c.
	Pressure.	Temperature.			
	U_1 (a)	U_1 (b)	U_2 (c)		
	"	°	°		
January	·02262	10·575	3·142	·0021	·0072
February	·02503	11·061	2·997	·0023	·0084
March	·03150	11·674	2·597	·0027	·0121
April	·03591	11·177	2·164	·0032	·0166
May	·03731	9·774	1·717	·0038	·0217
June	·03277	6·907	1·302	·0047	·0252
July	·02615	4·460	0·900	·0059	·0291
August	·02758	4·474	1·042	·0062	·0265
September	·02899	6·202	1·525	·0047	·0190
October	·02769	9·402	2·506	·0029	·0110
November	·02505	11·287	3·341	·0022	·0075
December	·02513	11·069	3·446	·0023	·0073

Comparison of U_1 of pressure with U_1 and U_2 of temperature.

Month	Tropical India, Inland. Pressure. U_1 (*a*)	Temperature. U_1 (*b*)	U_2 (*c*)	Ratio of *a* to *b*	Ratio of *a* to *c*.
	"	°	°		
January	·02754	11·307	2·664	·0024	·0103
February	·03177	12·388	2·788	·0026	·0114
March	·03580	13·753	2·687	·0029	·0133
April	·03585	11·437	2·745	·0031	·0131
May	·03424	10·416	2·338	·0033	·0146
June	·02292	6·468	1·697	·0035	·1053
July	·01615	4·886	1·425	·0033	·0113
August	·02061	5·538	1·510	·0037	0·136
September	·02473	6·313	1·795	·0039	·0138
October	·02617	7·357	2·011	·0036	·0130
November	·02558	8·915	2·206	·0029	·0116
December	·02335	9·814	2·367	·0024	·0099

The data for Extra-Tropical India indicate that for at least half of the year the variation of U_1, the first component of pressure, is inverse in character to that of the variation of U_1 for temperature. Thus from March to May U_1 for pressure is increasing while that for temperature is decreasing. Similarly from September to November, U_1 for pressure is decreasing whilst that for temperature is increasing. The opposite relation obtains during the remaining months of the year. The comparison between U_1 of pressure and U_2 of temperature for Extra-Tropical India approximately gives similar results. They increase or decrease together in five months and vary inversely in seven months. The comparison of the corresponding data for Tropical India shows a similar absence of invariable relation between the actual variation of U_2 of temperature and of the first component of the pressure oscillation.

The following gives a similar comparison for U_2 of pressure and U_1 and U_2 of temperature:—

Month.	Extra-Tropical India, Inland. Pressure. U_2 (*a*)	Temperature. U_1 (*b*)	U_2 (*c*)	Ratio of *a* to *b*.	Ratio of *a* to *c*.
		°	°		
January	·03722	10·525	3·149	·0035	·0118
February	·03851	11·061	2·997	·0035	·0128
March	·03869	11·674	2·597	·0033	·0149
April	·03720	11·277	2·164	·0033	·0172

Month.	Extra-Tropical India, Inland. Pressure. U_2 (*a*)	Temperature. U_1 (*b*)	U_2 (*c*)	Ratio of *a* to *b*.	Ratio of *a* to *c*.
	″	°	°		
May	·03400	9·774	1·717	·0035	·0198
June	·03113	6·907	1·302	·0045	·0239
July	·02928	4·460	0·900	·0066	·0325
August	·03253	4·474	1·042	·0073	·0312
September	·03535	6·202	1·525	·0057	·0232
October	·03538	9·492	2·506	·0037	·0141
November	·03606	11·267	3·341	·0032	·0108
December	·03633	11·069	3·446	·0033	·0105

Month.	Tropical India, Inland. Pressure. U_2 (*a*)	Temperature. U_1 (*b*)	U_2 (*c*)	Ratio of *a* to *b*.	Ratio of *a* to *c*.
	″	°	°		
January	·04532	11·307	2·664	·0040	·0170
February	·04749	12·388	2·786	·0038	·0170
March	·04767	12·253	2·687	·0039	·0180
April	·04408	11·437	2·745	·0039	·0161
May	·04058	10·416	2·338	·0039	·0174
June	03397	6·468	1·697	·0053	·0200
July	·03349	4·886	1·425	·0069	·0238
August	·03761	5·558	1·510	·0068	·0249
September	·04189	6·313	1·795	·0066	·0233
October	·04431	7·357	2·011	·0060	·0220
November	·04371	8·915	2·206	·0049	·0198
December	·04371	9·814	2·367	·0045	·0185

The annual variation of U_2 for pressure agrees more closely with that of either U_1 or U_2 of temperature than was the case with U_1 for pressure.

Thus in Tropical India the monthly values of U_2 for pressure and U_1 of temperature increase or decrease together in nine months, and vary inversely in three months only. Similarly the monthly values of U_2 of pressure and temperature vary directly together in nine months and inversely in three months.

There is hence no simple and direct relation between the amount of the variation from month to month of these elements.

Hence it may be inferred from this comparison that the amplitude of neither the first nor the second component of pressure is a direct function of either the actual temperature variation or of the variation of the first or second components into which the temperature variation can be resolved by Bessel's method.

D. Air movement.—It has been stated more than once that the pressure changes due to the variation of the temperature of the atmosphere at any place would, if there were no air movement, consist of a single oscillation of large amplitude, the maximum and minimum of which would be at the epochs of highest and lowest temperature during the day. The actual variation differs very largely from the above due to the large general air movements initiated by the pressure changes accompanying increase and decrease of temperature and of density of the atmosphere.

Character of movement due to mass absorption.—This absorption occurs throughout the whole mass depending upon various factors the laws of which have not yet been worked out. The chief feature is that under similar weather conditions such as, for instance, obtain in fine weather during the dry season over the whole of India and the adjacent seas the total diurnal amount of mass absorption varies little from place to place in India. The only important variation is in the epochs which occur at very approximately the same instants of local time, and which are hence transmitted westwards with *the apparent velocity of the sun in its diurnal march.*

The effect of expansion in giving rise to a displacement of the isobars in the vertical direction and *to movement is fully explained in various meteorological text books. In* considering the question it is best to limit the atmosphere by say the isobar of 0·1," which is probably at a mean elevation of at least 30 miles.

This isobar will be elevated above its mean position during the day hours and depressed below during the night hours. If we consider only the effect of the second component *of the* temperature variation, this variation will occur twice in the day, the result being the apparent transmission of a wave the crests and hollows of which will be separated by time intervals of six hours. The same will be true for lower isobars but the amplitude of the vertical movement will decrease downwards and be *nil* at the earth's surface. At any instant there will be a tendency to movement of the air from the crests to the hollows which will give rise to a forward and backward movement of the atmosphere. Data have been already given which indicate (but do not prove as they are only based on assumption) that the total forward or backward movement of the air particles is probably small in amount.

Theory hence appears to establish that any horizontal movement due to this action in the upper atmosphere (*where it will be greatest*) *will be very small* in amount, so small that it is very doubtful whether observations of the cirrus clouds will ever be sufficiently exact to show a corresponding diurnal variation. If the amount *of the* movement be relatively small in the upper strata of the atmosphere, it will evidently be much smaller in the lower strata In other words, there is almost certainly no large general periodic mass movement over India from east to west during one part of the day and from *west to east* in another part of the day which affects (increases or diminishes) the general eastward movement of the upper atmosphere (as indicated by observations of the highest cirrus clouds) from west to east.

in the equatorial regions a secondary maximum in August or September and a secondary minimum in December or January.

(8) U_1 is three times more variable in its amount than U_2.

(B) Phases (u_1) and epochs of the first component :—

(1) The mean value of u_1 is 360° and very nearly corresponds to a maximum epoch of 6 A.M. It is fairly constant in low latitudes (0° to 35°).

(2) The mean value of u_1 is 13° in mountain valleys (corresponding to the epoch of the maximum phase at 5 A.M.).

(3) The mean value of u_1 for stations on mountain peaks is 280° (differing, however, considerably with elevation). This corresponds to a maximum epoch of 11-20 A.M. Hence the maximum phase is greatly retarded on mountain peaks and is slightly accelerated in mountain valleys.

(4) u_1 varies very irregularly, even at neighbouring stations and under apparently similar circumstances.

(5) u_1 shews great irregularities in its variation throughout the year.

(6) In general it may be stated that the daily oscillation of the barometer in mountain valleys is almost normal, with the exception of a very large increase of the amplitude of the 24-hour wave.

(7) The epochs of the first component are six times more variable than those of the second component.

(C) Amplitude of the second or twelve-hourly component (U_2) :—

(1) There is in equatorial regions a well-marked double annual variation in the amplitude U_2 of the second component, the maxima of which are in March or April, and August or September, and the minima in June or July, and November or December. The law for the annual variation of U_2 within the tropics is :—

$U_2 = {}^{\cdot}0338 + {}^{\cdot}0017 \sin. (92° 30' + 30°x) + {}^{\cdot}0025 \sin. (287° 22' + 60°x)$, where x represents time in months.

(2) The most characteristic feature of the yearly variation of the amplitude U_2 is the occurrence of the maximum values at the spring and autumn equinoxes when the sun is vertically over the equator. The epochs of the minima values are June and December (almost without exception). The amplitude U_2 is smaller at all stations for June than for December, thus establishing that there is a period of variation corresponding with the least and greatest distances of the sun.

(3) U_2 is slightly increased in mountain valleys and slightly diminished below its normal value at stations in the interior of continents, and also relatively to the coast stations in higher latitudes.

(4) U_2 has (abnormally) large values in India or, assuming the normal values derived from the formula given in (6) or the data in (7) in the following page, the amplitudes of Indian stations are greater than those values as given by the latitudes of the stations.

(5) The amplitude of the second or twelve-hourly component of the diurnal pressure oscillation decreases in the tropics with elevation in the same latitude

Character of movement due to surface absorption.—The movement due to surface absorption differs entirely from the preceding which is perfectly general and occurs equally over land and sea. This movement is due to the unequal heating of land and sea surfaces and also of different portions of the land surface. This action gives rise to rapid upward convective movements with the attendant inflow below and outpour above. This action extends to very different heights during the day and attains its greatest elevation shortly after the hottest time of the day and even in the height of the hot season in India, rarely extends above two miles. It is hence confined to the lower portion of the atmosphere and includes vigorous irregular uptake over the land area, the volume and intensity of which have a variation following closely the heating of the ground surface and of an outflow above to the adjacent sea areas chiefly and an inflow below from the adjacent sea areas. The whole movement has a well marked diurnal variation the character of which is given by the diurnal variation of velocity in the lowest atmospheric strata. Charts illustrating this feature at 15 stations for the four seasons of the year are given in Plates LIII to LVI

The diurnal variation of wind velocity due to this action is probably found in its simplest form in India at central stations, *e.g.*, Agra, Lucknow, Lahore, Jubbulpore and Nagpur. The representative curves for these stations are not simple harmonic. The chief features are nearly constant velocity during the night hours, a rapid increase commencing about 8 A.M. (varying slightly with the season) to a maximum between 3 P.M. and 4 P.M. and a rapid decrease until 8 or 9 P.M. The day actions hence impress a large 12-hour variation in the velocity the epochs of which correspond with the day variation of temperature and pressure.

It may perhaps be possible later to eliminate the total movement in the lowest strata due to expansion of the air (and the general wave movement) the intensity of which probably does not vary much during the whole 24 hours period from the mean night air movement and thus obtain an approximate estimate of the horizontal movement due to convective action.

A comparison of the curves giving the annual variation of the lower air movement at twenty-nine stations (*vide* Plate LII) with the curves giving the annual variation of the amplitude of the first component (*vide* Plates LXV to LXVII) suggests the following inferences :—

(1) There is no direct relation between the annual variation of the average wind velocity and the variation of the amplitude of the first component of pressure, a large variation in the air movement occurring with small variation of the amplitude of the first component, and *vice versâ*. The curves for Kurrachee, Lahore, Jaipur, Allahabad, Rangoon, Madras and Belgaum illustrate this.

(2) Both sets of curves agree in showing a pronounced maximum and minimum corresponding to the characteristic contrast between the dry (cold or hot) weather and the rains, but the epochs do not agree even on the assumption of an inverse relation.

(3) In addition many of the curves show a secondary variation at the end of the rains, of which there is no trace in others, *e.g.*, Jaipur, Allahabad, Belgaum, Chittagong, Rangoon and Bellary. At the Deccan stations, more especially

Poona, Belgaum and Bombay the curves of the first component for pressure are roughly the inverses of the wind variation curves. The curves have in common one epoch, *viz.*, the July epoch of maximum of air movement and of minimum amplitude of the first pressure component. They differ however widely in the second critical epoch, the minimum of wind velocity occurring in October or November and the maximum of the amplitude of the first component in April.

Hence the want of correspondence between these two elements indicates that there is no simple direct or inverse relation between the first component of diurnal variation of pressure and of the lowest air movement.

A reference to the curves in Plates LII and LXV to LXVII shows that there is an imperfect inverse correspondence between the annual variation of wind velocity and of the amplitude of the second component of the diurnal oscillation of pressure.

There is a moderate inverse correspondence in the case of the following stations, *viz.*, Lahore, Jaipur, Allahabad, Calcutta, Jubbulpore and Nagpur. There is, however, at each of these stations a slight oscillatory variation at the end of the rains in the pressure curves which has no corresponding variation in the wind velocity curve.

In the cases of Rangoon and Madras, the two curves differ so widely as to indicate no relation.

At the Bombay and West Deccan stations (Poona and Belgaum) there is a very large variation in each of the curves, the epochs of which are approximately coincident and the annual variation in each similar in amount.

Hence there is no definite relation between the annual variation of the air movement of the lowest atmospheric strata and of the amplitudes of the first and second components of pressure and hence the latter cannot be expressed as functions of the former.

It may also be noted here that I have examined the constants of the periodic formula for the diurnal variation of the north and east components of the wind direction (1) according to direction only, and (2) according to direction and amount of movement and found that there is no general agreement between the epochs of either the first and second components and the epochs of the first and second components of the pressure oscillation. The epochs in the former case differ so much from station to station as to show that local conditions are a most important element. The variability it may be noted, is much larger for the northerly than the easterly component, and for the first than for the second component of the Besselian resolution of each of the 13 stations for which the data have been tabulated. The epoch of the second Besselian epoch ranges generally between 8 A.M. and 10 A.M. and averages 9 A.M. These stations include all in Northern India. There is a strongly marked tendency for the maximum of the second component of the wind to occur at 9-22 A.M. or almost at the same time as the maximum or the second component of the pressure oscillation. Whether this is more than a mere coincidence cannot be established until the problem has been discussed by hydrodynamical methods.

I have also had the annual variations of wind velocity for eight stations worked out

by Bessel's method The following gives the epochs of the maximum and minimum values of the first and second components on the mean day of year

Station	Epochs of the first component of wind velocity on the mean day of year		Epochs of the second component of wind velocity on the mean day of year	
	North component of wind velocity	East component of wind velocity	North component of wind velocity	East component of wind velocity
Calcutta (Alipore) . . .	6·45 A.M.	2 0 A.M.	1 54 A.M. & P.M.	7 8 A.M. & P.M.
Saugor Island . . .	8 43 "	5 58 "	9 13 " "	6·42 " "
Kurrachee . .	3·59 "	5 54 "	8·23 " "	9 10 " "
Deesa	3 34 "	6 31 "	8 2 " "	0·9 " "
Jaipur . .	11·33 "	2 6 "	4 22 " "	7 51 " "
Hazaribagh . .	2 38 P.M.	0 3 "	2·38 " "	8 2 " "
Poona	8 18 "	6 13 "	7 38 " "	0·17 " "
Leh	0·43 A.M.	3 52 "	6 39 " "	10·4 " "

I have endeavoured to show that the interchange of air movement between the land and sea is at all times of the year much greater in India than has probably been supposed, and that it is necessary to take this for granted to explain many meteorological actions in India.

It is possible that it is the inter-movement between land and sea which is almost as vigorous in the dry as in the wet season that explains the character of the second component of pressure to which Dr Hann has called attention, *viz*, the excess in South Asia, more especially India (*vide* page 322, C(4)).

This day movement accompanies a considerable variation in the relative distribution of pressure which, as might be expected, is least marked in the height of the rains and most pronounced in the hot weather. An examination of the Plates L and LI will show the modification of the average distribution of pressure produced or effected by the heating of the atmosphere during the day hours and accompanying air movements. The April Charts, figs 3 and 4, Plate L, are most instructive from this point of view

It may be interesting to note the following different relations which obtain in different parts of India At Bombay, Belgaum and Poona the least amplitude of the first and second components of the pressure oscillation occurs with the greatest wind velocity. In Northern India, on the other hand, the maximum velocity occurs in the hot weather and is practically coincident with the maximum amplitude of the first component but from one to two months after the maximum of the second component Similarly the minimum air movement occurs over nearly the whole of India in the month of November, the month of greatest serenity, least cloud and greatest diurnal range of temperature This is two months earlier than the epoch of the minimum amplitude of the first component

The curves in Plates LIII to LVI representing the diurnal variation of velocity at fifteen stations in each of the four seasons of the year are interesting The curves for the interior stations of Northern and Central India and the Central Provinces stations show that in all seasons the air movement is almost constant during the night hours from about 7 P.M. on the average to 7 A.M. It increases from about 7 A.M. to about 2 P.M. and thence decreases to 7 P.M. following the intensity of solar radiation with a

retard of about 1 to 2 hours but otherwise varying in total amount parallel with the variation of the solar action.

The representative curves for the coast stations are quite different in character. In certain seasons, as for example for Bombay, *vide* Figs. 15 and 16 in Plate LV, they show very clearly the double variation of velocity during the 24 hours period accompanying the prevalence of land and sea breezes. The following gives the mean velocity at 4 A.M., 10 A.M., 4 P.M. and 10 P.M. for the three stations of Jaipur, Nagpur and Patna, stations fairly representative of the interior of India.

Hour.	Mean hourly wind velocity on the mean day of the year at		
	Jaipur.	Nagpur.	Patna.
4 A.M.	3·93	3·74	2·28
10 A.M.	7·69	6·00	3·55
4 P.M.	7·09	6·25	3·37
10 P.M.	4·08	3·68	2·12

In addition to the general movements that have been considered, there are two other movements, special and local, in character, which require to be taken into consideration. These are:—

(1) Mountain area winds.

(2) Land and sea breezes.

The former have been dealt with by Dr. Hann so far as they relate to the movements due to what may be termed valley conditions and actions. He does not take into consideration the general circulating movement between the mountain districts of North-Western India and the adjacent plains. It is, however, similar in general character and also in its epochs to the second class of movement.

An examination of the pressure charts indicates that in the area to which the sea winds extend during the day hours there appears to be a local relative decrease of pressure over the coast and adjacent districts (very marked over the West Ghâts during the afternoon hours). The opposite appears to be the case in the early morning hours and probably up to 9 A.M. or 10 A.M. So that there is an exaggeration of the general high pressure conditions obtaining at about 10 A.M. and of the low pressure conditions obtaining at about 4 P.M. The chief effect of this will apparently be to increase considerably the amplitude of the second component. The effect will depend largely upon the critical epochs of this action but it appears to explain more or less fully the large amplitude of the diurnal oscillation at Kurrachee, Poona, Belgaum and Bombay. The subject deserves fuller consideration than can be given to it in this Memoir.

It would hence follow as a general rule that any local conditions which would modify the horizontal movement, either increasing or retarding it, would modify the amplitude of the diurnal variation.

The following illustration of the effect of local conditions in modifying pressure is interesting. Dehra Dun, Ajmer, Salem and Jaipur are more or less shut in by hills, to

such an extent that the horizontal movement set up by the increasing heat is more or less retarded. As a consequence pressure increases to a greater extent in the morning hours than at open stations. The following gives the average local increase of pressure due to this cause at 8 A.M. for each month of the year deduced by a comparison of the latest averages.—

Month	Dehra Dun	Ajmere.	Salem
	"	"	"
January . . .	+·020	+·040	+·010
February . . .	+·020	+·035	+·030
March	+·020	+·030	+·030
April	+·020	+·030	+·030
May	+·020	+·020	+·030
June	+·030	+·030	+·020
July	+·020	+·030	+·030
August	+·030	+·030	+·030
September	+·030	+·030	+·040
October	+·020	+·030	+·030
November	+·010	+·040	+·030
December	+·020	+·030	+·030
Mean .	+·020	+·031	+·028

Variation of amplitude of diurnal oscillation with sunspot period—If the slight variation of the sun's distance is able to impress itself on the second component, it might reasonably be expected that the variation of the sunspots would give rise to a change of corresponding period in the diurnal oscillation, more especially in its amplitude.

The following gives annual values of the mean annual amplitude of the total oscillation for the Calcutta, Bombay and Madras observatories (as obtained from 10 A.M. and 4 P.M. observations) for the whole period for which observations are available.—

				ANNUAL RANGE OF AIR PRESSURE.															
				CALCUTTA.					BOMBAY.					MADRAS					
Cycle 1.	Cycle 2.	Cycle 3.	Cycle 4.	Cycle 1	Cycle 2	Cycle 3.	Cycle 4.	Mean.	Cycle 1	Cycle 2.	Cycle 3	Cycle 4	Mean.	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Mean
				"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
1867*	1878*	1889*	1900*	·113	·118	·116	113	113		·106	104	109	103		·118	·112	·124	·118
1868	1879	1890		116	·117	·113		115		103	101		·102	117	116	·110		·114
1869	1880	1891		·118	117	·112		116		103	101		102	·116	124	?		·120
1870†	1881	1892		·119	117	·119		118		·099	104		102	113	118	·107		113
1871†	1882	1893		114	118	108		113		107	109		108	117	122	·113		118
1872†	1883†	1894		·117	·116	117		117		·103	·108		·103	113	·120	112		115
1873	1884†	1895		117	·119	113		117		104	102		103	118	·123	114		118
1874	1885	1896		·118	·112	113		114		·100	·103		103	·116	·129	·115		120
1875	1886	1897		117	·112	·118		116	105	106	·103		104	119	·121	·116		·119
1876	1887	1898		·114	109	·113		112	·100	105	102		102	·120	·121	·116		119
1877*	1888*	1899*		109	·116	·113		·111	103	100	103		102	115	109	114		·113

* Minimum sunspot years. † Maximum sunspot years.

The previous data show that there is a slight tendency to increased amplitude about the maximum of the sunspot period and to decreased amplitude about the minimum of the sunspot period. The variation is small in amount and somewhat irregular in character (the data, it may be noted, have not been smoothed) and it is doubtful whether the data are sufficient in amount to establish the inference named above.

Conclusion.—The preceding discussion appears to have established that there is no direct relation between the diurnal oscillation of pressure, either in its complete form or in its components, and any one of the following elements, *viz.*, temperature, aqueous vapour pressure, cloud or air movement so that the annual variation of the amplitudes and epochs of any of these elements cannot be expressed in terms of the variation of one of the remaining elements. They are more or less related, the connecting link being the air movements set up, chiefly by variations of temperature and aqueous vapour pressure.

On the other hand, the diurnal and annual variations of the pressure oscillation have been shown to vary more or less directly with the changes and variations of energy due to the processes of absorption by the atmosphere of solar and terrestrial radiation and to atmospheric emission of radiation to the ground surface and space. The parallelism, more especially in the case of the annual variation of the first component, is very close and suggestive of a direct connection and relation.

It has also been pointed out that the whole variation of energy is due to practically independent variations, *viz.*, (1) Mass absorption and radiation, and (2) surface absorption and radiation and their redistribution by the air movements set up and that the former gives rise chiefly to the second term or element of the Besselian expression of the diurnal pressure oscillation and the latter to the first term. Of the two processes of absorption, the latter varies much more largely and irregularly with the season and latitude than the former which is in close agreement with the most pronounced features of the first and second components.

These processes are largely dependent upon the great seasonal variations in India, and hence we find both the first and second components vary in their intensity with the broad seasonal changes in India.

It hence appears that the consideration of the question from the standpoint of the variation of energy of the atmosphere due to solar terrestrial and atmospheric radiation accounts generally for the more important phenomena of the diurnal oscillation of pressure in India and that further investigation of these factors and the accompanying air movement throughout the mass of the atmosphere will probably contribute largely towards the solution of the problem.

The last chapter of the present discussion was chiefly written during a prolonged tour over the whole of India from November 1901 to March 1902. It is, I am fully aware, very imperfect and perhaps very hastily prepared. It is however necessary to complete its publication before I go on leave in May 1902 and I am hence compelled to issue it in its imperfect state in the hope that I may perhaps be able to take up the discussion from the same or a similar standpoint at some future time and thus complete the present investigation.

G. I. C. P. O.—No. 5 Meteor.—15-7-02—340.

Brief description or explanation of plates VI to LXXIII in Vol. XII, Part III, of the "Indian Meteorological Memoirs"

Plate VI	Figs.	1—15	Diurnal variation of the mean excess of maximum insolation temperature at the hours of apparent time in three seasons of the year for five stations
" VII	"	1—12	Diurnal variation of the mean excess of maximum insolation temperature at the hours of apparent time in three seasons of the year for four stations.
" VIII	"	1—7	Diurnal variation of the air temperature, surface temperature and surface minus air temperature at Jaipur in December and May (1885,) and at Allahabad in May (1900) and the annual variation of mean monthly maximum difference of ground and air temperatures at Jaipur (1885)
" IX	"	1—9	Diurnal variation of the air temperature and surface temperature and also of the surface minus air temperature at Jaipur in January, April and July (1885)
" X	"	1—11	Annual variation of temperature at twenty-eight stations.
" XI	"	1—17	
" XII	"	1—14	Annual variation of the mean daily range of temperature at twenty-nine stations.
" XIII	"	1—15	
" XIV	"	1—24	Diurnal variation of temperature in four seasons of the year and in the year, and rate of change of temperature for the year for the four divisions of India
" XV	"	1—21	Diurnal variation of temperature for three periods of the year, (viz., the cold weather and hot weather periods and the period including the months of June and September) at twenty eight stations.
" XVI	"	1—21	
" XVII	"	1—21	
" XVIII	"	1—21	
" XIX	"	1—21	Diurnal variation of temperature for two periods of the year (viz., the period including the months of July and August and the retreating south west monsoon period) and for the year at twenty-eight stations.
" XX	"	1—21	
" XXI	"	1—21	
" XXII	"	1—21	
" XXIII	"	1—15	Annual variation of vapour pressure at fifteen stations
" XXIV	"	1—17	Diurnal variation of vapour pressure according to types for each of the four seasons of the year
" XXV	"	1—30	Diurnal variation of vapour pressure for three periods of the year, viz., January and February, March to May, and June and September at twenty eight stations.
" XXVI	"	1—27	
" XXVII	"	1—27	
" XXVIII	"	1—30	Diurnal variation of vapour pressure for two periods of the year, viz., July and August, and October to December and for the year at twenty eight stations
" XXIX	"	1—27	
" XXX	"	1—27	
" XXXI	"	1—13	Diurnal variation of vapour pressure at Srinagar (*Kashmir*) for each month of the year and the year.
" XXXII	"	1—30	Diurnal variation of humidity for three periods of the year (viz., January and February, March to May, and June and September) at twenty-seven stations.
" XXXIII	"	1—27	
" XXXIV	"	1—24	
" XXXV	"	1—30	Diurnal variation of humidity for two periods of the year, viz., July and August, and October to December and for the year at twenty-seven stations.
" XXXVI	"	1—27	
" XXXVII	"	1—24	
" XXXVIII	"	1—15	Annual variation of cloud for twenty nine stations
" XXXIX	"	1—14	
" XL	"	1—20	Diurnal variation of cloud according to types for each of the four seasons.
" XLI	"	1—28	Diurnal variation of cloud for two periods of the year (viz., January and February and March to May) at twenty seven stations
" XLII	"	1—26	
" XLIII	"	1—28	Diurnal variation of cloud for two periods of the year (viz., June and September, and July and August) at twenty seven stations
" XLIV	"	1—26	

Plate XLV . . „ XLVI . .	Figs. „	1—28 1—26	Diurnal variation of cloud for the period October to December and for the year at twenty-seven stations.
„ XLVII . .	„	1—13	Diurnal variation of cloud at Srinagar (*Kashmir*) for each month of the year and the year.
„ XLVIII . .	„	1—4	Chart showing normal mean pressure and winds for January, March, May and June.
„ XLIX . .	„	1—4	Chart showing normal mean pressure and winds for August, October, December and year.
„ L . . .	„	1—4	Chart showing normal pressure and winds at 8 A.M. and 4 P.M., in January and April.
„ LI . .	„	1—4	Chart showing normal pressure and winds at 8 A.M., and 4 P.M., in July and November.
„ LII . .	„	1—29	Annual variation of wind velocity in miles per hour for twenty-nine stations.
„ LIII . . „ LIV . .	„ „	1—16 1—14	Diurnal variation of wind velocity in miles per hour in two seasons (*viz.*, the cold weather and hot weather seasons) for fifteen stations.
„ LV . . „ LVI . .	„ „	1—16 1—14	Diurnal variation of wind velocity in miles per hour in two seasons (*viz.*, the south-west monsoon and retreating south-west monsoon periods) for fifteen stations.
„ LVII . . „ LVIII . . „ LIX . .	„ „ „	1—30 1—30 1—30	Diurnal variation of pressure for three periods of the year, (*viz.*, January and February, March to May and June and September) at thirty stations.
„ LX . . „ LXI . . „ LXII . .	„ „ „	1—30 1—30 1—30	Diurnal variation of pressure for two periods of the year (*viz.*, July and August, and October to December) and for the year at thirty stations.
„ LXIII . .	„	1—13	Diurnal variation of pressure at Srinagar (*Kashmir*) for each month of the year and the year.
„ LXIV . .	„	1—8	Diurnal variation of the air and surface temperature at Jaipur in December, May, July and August.
„ „ . .	„	9 and 10	Diurnal variation of the air temperature and of the rate of change of the air temperature in Northern India in the dry season.
„ „ . .	„	11 and 12	Diurnal variation of the maximum insolation temperature and of the rate of change of the maximum insolation temperature in Northern India in the dry season.
„ LXV . . „ LXVI . . „ LXVII . .			Annual variation of the amplitudes of U_1 and U_2 of air pressure and temperature, maximum insolation temperature and diurnal range of temperature for fifteen stations.
„ LXVIII . . „ LXIX . . „ LXX . .			Annual variation of temperature, aqueous vapour pressure and cloud and the amplitudes of U_1 and U_2 of aqueous vapour pressure for fifteen stations.
„ LXXI . .			Annual variation of the amplitudes of U_1 and U_2 of cloud proportions at seven stations.
„ LXXII . .	„	1—6	Diurnal variation of U_1, U_2 and U_3 *plus* U_4 of pressure for the typical months of the three seasons of the year at Jaipur and Allahabad.
„ LXXIII .	„	1—6	Diurnal variation of U_1, U_2 and U_3 *plus* U_4 of temperature for the typical months of the three seasons of the year at Jaipur and Allahabad.

DIURNAL VARIATION OF MEAN EXCESS OF INSOLATION TEMPERATURE AT THE HOURS OF APPARENT TIME IN,-